Appendix E: Climate impacts and adaptation actions for Canada lynx

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, vegetation systems, and regions chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the Canada lynx (*Lynx canadensis*).

Photo: Eric Kilby

Figure E.1. Canada lynx

The Canada lynx is a wide-ranging carnivore with relatively high sensitivity to anthropogenic fragmentation. In the transboundary region of Washington and British Columbia, the lynx's coniferous, early seral stage forest habitat exhibits low connectivity.[2] Barriers to lynx movement are presented by both natural factors (e.g., large lakes and high topographic relief) and human factors (e.g., snow compaction associated with winter recreation), with significant barriers present along major highways and the Okanagan Valley (Appendix E.1).[2]

Future climate change may present additional challenges and needs for Canada lynx habitat connectivity.[3-4] First, climate change may impact lynx core habitat and dispersal corridors in ways that make them more or less permeable to movement. Second, existing lynx core habitat and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in lynx distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for lynx habitat connectivity in this region. To address these needs, we describe here a novel effort to identify and address potential climate impacts on lynx habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary lynx habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence lynx habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix E.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The lynx conceptual model was developed using peer-reviewed articles and reports, project participant expertise,

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[i] This report is Appendix E of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to lynx habitat connectivity.

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on lynx habitat connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

Key impacts on transboundary Canada lynx habitat connectivity identified via this approach include changes in areas of climatic suitability for Canada lynx, changes in forest habitat, changes in disturbance regimes, and declines in the amount and duration of snowpack.

Changes in areas of climatic suitability

Climate change may impact lynx habitat connectivity by changing the extent and location of areas of climatic suitability for lynx; this may render some existing core habitat areas and corridors unsuitable for lynx, and/or create new areas of suitability. Climatic niche models provide estimates of species' current and projected future areas of climatic suitability, and are available for lynx for the 2080s based on two CMIP3 Global Circulation Models (GCMs) (CGCM3.1(T47) and UKMO-HadCM3[ii]) under the A2 (high) carbon emissions scenario[iii] (Appendix E.3).

For both climate models, projections for the 2080s show a decline in climatic suitability for lynx in the mid- to low-elevations of the Columbia, Monashee, and Selkirk Mountains, the low-elevations of Colville National Forest, river valleys, and the Okanagan Valley in particular. Corridors crossing these valleys (especially the Okanagan) may currently be important for maintaining connectivity among lynx populations at higher elevations. This decline is more extensive for the CGCM3.1(T47) model. Projected declines in climatic suitability in valleys suggest that valley crossings by lynx may become more difficult in the future, further isolating higher elevation populations separated by valleys. Some fragmented areas in the higher elevations persist.

[ii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

For both climate models, the climatic niche model projects increases in climatic suitability for some areas in the transboundary region west of the Okanagan Valley. Currently suitable habitat in these areas is expected to remain stable and possibly expand in climatic suitability.

Changes in forest habitat

Throughout their range, lynx use cold, moist vegetation in regenerating and multi-layer mature forests.[11] Changes in the distribution and quality of forest habitats in the transboundary region could therefore be expected to affect lynx habitat connectivity. Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models (Appendix E.4).[iv]

Within the transboundary region, lynx's current range is projected to remain needle-leaf forest, though the character of that forest may change. Mechanistic vegetation models for this region show a contraction of boreal needle-leaf ("cold") forest and alpine habitat types, which are replaced by temperate needle-leaf ("cool") forest (Appendix E.4). While lynx are predominantly associated with boreal (or subalpine) forest types,[2] the current mapped range for lynx encompasses both forest types, so it is difficult to judge how significant of an impact this would have on lynx habitat quality. Climatic niche models project a contraction of subalpine and alpine vegetation and expansion of coastal conifer forest, low to mid-elevation conifer forest, or no analog vegetation types (i.e., areas for which future climate does not closely match that the current climate of an existing vegetation type), depending on the location and climate scenario (Appendix E.4).

Changes in disturbance regimes

Climate change may affect lynx habitat connectivity by increasing the frequency and severity of summer drought (Appendix E.6: Dry Spell Duration), increasing the risk of wildfires (Appendix E.6: Days with High Fire Risk), and influencing pest and pathogen dynamics. Drier conditions could reduce the amount and/or quality of moist habitats and forests. A longer fire season and increase in area burned could also affect forest habitat.[12] Moisture stress and fire can increase tree mortality and bark beetle outbreaks (Appendix E.5), which can further increase the chances of large, high-intensity fires. Such disturbance events could affect lynx habitat connectivity by reducing the amount and/or quality of available core forest habitat and movement corridors.

How projected changes in fire regimes affect lynx habitat connectivity will depend on fire return intervals, severity, size, location, and the subsequent successional trajectories of vegetation (Appendix E.4 and Appendix E.6: Days with High Fire Risk). While lynx avoid recently burned areas (likely due to insufficient vegetative cover), once cover reestablishes in regenerating forests, these environments can be beneficial to lynx habitat connectivity.

[iv] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

Declining amount and duration of snowpack

Projected declines in the amount and duration of snowpack and increases in the ratio of snow to water precipitation (Appendix E.6: Spring (April 1st) Snowpack; Length of Snow Season; Ratio of April 1st Snowpack to Winter Precipitation) may affect the quality of lynx core areas and corridors. Morphological adaptations, such as a low foot-loading (ratio of body mass to foot area), enable lynx to outcompete other predators in areas with deep, unconsolidated snow.[13] Declining amount and duration of snowpack could thus result in a contraction of lynx core habitat, and increasing fragmentation and isolation of core areas within the current southern periphery of the lynx range. Declines in snowpack amount and duration could also make it harder to set prescribed fires to reduce wildfire risks.

Adaptation responses

After identifying potential climate impacts on lynx habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix E.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on lynx habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in lynx distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on Canada lynx habitat connectivity

Actions to address the potential for lynx habitat to become increasingly isolated and fragmented include:

- Managing forestry activities to ensure that forest canopy and understory cover remain continuous throughout lynx corridors (Appendix E.1) and that woody debris remains present.

- Considering limiting all-terrain-vehicle use within climate resilient core habitat areas and corridors.

- Avoiding development of new roads through existing or potential future movement corridors (Appendix E.1). If roads are present, consider installing crossings.

Actions to address the potential for valley bottom crossings to become more difficult as low elevation valleys become warmer and drier include:

- Identifying and protecting corridors likely to facilitate lynx movement across low elevation valleys, in order to maintain connectivity among higher elevation core habitat areas. Habitat connectivity models (Appendix E.1) could be used to evaluate low-elevation corridors for key areas where continued permeability will be especially important to maintaining broader connectivity, and which should thus be high priorities for connectivity conservation efforts.

- Focusing habitat retention efforts in valleys on riparian habitats; lynx frequently utilize these for dispersal through dry habitats, which may become less permeable to lynx movement as climate warms.

- Monitoring low-elevation corridors for vegetation changes that may affect lynx connectivity. If shrub steppe vegetation appears to be expanding, cross-valley corridors may become longer, making them less attractive to dispersing lynx. Conversely, if forest expands into the valley, corridor suitability may increase for lynx. Monitoring would allow timely modification of connectivity conservation efforts to account for these or other possible changes.

Actions to address the potential for climate change to impact connectivity through more frequent and severe wildfires include:

- Using rotating, targeted fuel reduction techniques and prescribed burns to create firebreaks and reduce the risk of catastrophic wildfires that could result in broad-scale loss of lynx habitat and corridors. Vegetation management strategies should simultaneously aim to preserve sufficient cover (understory and woody debris) for lynx and snowshoe hares (i.e. thinning and other fuel reduction strategies should also consider stand diversity and habitat goals).

- Incorporating projections and observations of changes in the length of the snow season, evapotranspiration, soil moisture deficits, and the timing of precipitation to inform the timing of fire prevention techniques as conditions change, in order to maximize their safety and effectiveness.

- Using some degree of fire suppression in cool, moist forests with long fire return intervals, such as those used by lynx. In contrast to drier, low elevation forests, suppressing fire in cool, moist forests is less likely to result in increased fuel loads over time (which can lead to subsequent increased fire risk years later).

- Referencing the forest and grazing practices of First Nations and tribes to identify traditional strategies for managing fire risk and other potential climate impacts.

Actions to address projected decreases in the depth and persistence of snowpack include:

- Using forest practices that promote snowpack retention (e.g. snow fences) at elevations used by lynx that are projected to experience the greatest decreases in snowpack, with the caveat that given the large home range sizes of lynx, local-scale snow management is unlikely to have a significant impact on lynx core habitat quality. Therefore, consider prioritizing such efforts within important habitat areas (e.g., near known denning sites) and corridors.

- Ensuring that moisture and snowpack retention practices (when implemented) are compatible with other forest management practices that balance the need for fire and natural resource management with the need for sufficient horizontal cover for lynx and snowshoe hares.

- Identifying areas where deep spring snowpack is most likely to persist in the future (Appendix E.5), such as north-facing slopes and topographically shaded areas (e.g., canyons). Consider directing snowpack retention efforts to these areas, and prioritizing them when managing for lynx core habitat and corridors.

Enhancing connectivity to facilitate range shifts

Actions that may help lynx adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- Maintaining and restoring corridors between areas of declining climatic suitability for lynx and areas of stability or increasing suitability (Appendix E.3).

- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors, Appendix E.1), to ensure that lynx have the ability to disperse into cooler, higher elevation habitats as the climate warms.

- Focusing habitat retention efforts on ridgelines; forested areas; valley bottoms; and riparian areas, which span climatic gradients and are used by lynx as movement corridors.

- Planning the placement, orientation, and shape of habitat reserve patches to maximize connectivity, span climatic gradients, and cross low-elevation valleys. As part of this, ensure that when clear cuts are made in forested lynx core habitat and corridors, reserve patches are connected by corridors.

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- High elevation peaks in the Rockies, the western half of the Okanagan Valley, and the North Cascades. Climatic niche model projections suggest that these areas are likely be climatically suitable in the future (Appendix E.3).

- The Okanagan Valley and other lower elevation areas in the greater Okanagan region. These areas already constrain lynx movement (Appendix E.1),[2] and are expected to become less climatically suitable for lynx as the climate warms (Appendix E.3). Maintaining and restoring connectivity across these valleys will be important for maintaining connectivity among higher elevation lynx habitats.

- Highways, especially those that run along low-elevation valleys (e.g., Highway 97 and Highway 3A) and those that cross the Cascade Range (e.g., Highway 3). These highways may present dispersal barriers among higher elevation habitats. For example, Highway 3 cuts east-west through E.C. Manning Provincial Park and may create a dispersal barrier for south-north movement through the North Cascades; if there is evidence that the road creates a barrier, it could be a candidate for a crossing.

- Climate-gradient corridors (Appendix E.1), which may help lynx shift its range into cooler habitats as climate warms.

- Ridgelines and forested riparian areas, which currently act as lynx movement corridors through dry elevation areas, and also span climatic gradients, facilitating dispersal into cooler habitats.

Policy considerations

Referrals response

Actions for addressing climate impacts on lynx habitat connectivity through First Nations and tribal referrals response processes include:

- For highway expansion projects, encouraging the use of highway design techniques that preserve connectivity (e.g., overpasses, open span bridges, and culverts), both on and off tribal and First Nation lands.

- Encouraging the incorporation of wildlife-friendly fencing into permitting and planning processes. Promoting the use of such designs may help facilitate lynx movement.

Land use planning and management

Actions for addressing climate impacts on lynx habitat connectivity though land and water use planning and management include:

- Striving for community designs that limit fragmentation of habitat and include habitat corridors. Keeping development away from potential lynx corridors.

- Using large parcel zoning to maintain contiguity of natural areas within First Nations and tribal lands. Outside of these lands, work with private landowners and with environmental policy to maintain contiguous swaths of suitable land that will facilitate connectivity**.**

- Coordinating with forest managers and planners to incorporate fire management recommendations into planning documents.

- Monitoring lynx habitats for suitability and preparing to address and/or modify the legal context for management. In the contiguous United States, the Canada lynx is listed as threatened under the Endangered Species Act, requiring protection of critical habitat; these areas may change with future warming.

- Reviewing and implementing existing guidance and plans relating to lynx habitat management. Evaluate existing recommendations for opportunities to address climate impacts.

- Investigating whether having multiple priority species affected in the same area can lead to greater pressure to change management practices if cumulative impacts can be demonstrated.

Transportation planning

Actions for addressing climate impacts on lynx connectivity through transportation planning include:

- Coordinating with transportation agencies to evaluate appropriate management responses to potential changes in seasonal road openings and closings within high value lynx habitat as snow conditions change.

- Coordinating with transportation agencies to ensure that new roads do not negatively impact climate-gradient corridors, or climate-resilient lynx core habitat and corridors (see Additional Research, below). When new roads are inevitable, mitigate barrier effects by incorporating crossing structures into road design.

Research Needs

Future research that could help inform lynx habitat connectivity conservation under climate change includes:

- Developing transboundary fire models. These models could improve assessment of potential impacts, and direct fire management activities toward core habitat areas and corridors identified as being at high fire risk.

- Developing transboundary pest models (e.g., mountain pine beetle, spruce budworm, and western pine beetle). These models could improve assessment of potential impacts, and direct forest health activities toward core areas and corridors identified as being at high risk of insect or pathogen outbreaks.

- Developing fine-scaled, transboundary riparian models. These could help identify high quality riparian corridors that could facilitate movement despite general regional warming.

- Gathering additional empirical data on transboundary lynx movement to validate and improve existing corridor models. Very little is known about how lynx select movement habitat and about lynx dispersal behavior more generally. Consequently, it is not clear to what extent lynx will move through sub-optimal habitat as it warms.

- Mapping current lynx population locations (as opposed to general range boundaries). This could help identify vulnerable populations and give a more realistic sense of existing and potential future connectivity.

- Identifying potential climate impacts on specific lynx core habitat areas and corridors. Overlay projected changes in climate with existing lynx corridor networks to quantify expected impacts

on specific areas within the network. This may help direct adaptation actions to appropriate areas.

- Identifying climate resilient lynx core habitat areas and corridors. Overlay corridor networks (Appendix E.1) with climatic niche models (Appendix E.3), and projected changes in vegetation (Appendix E.4), mountain pine beetle survival (Appendix E.5), and climatic variables (Appendix E.6); core areas and corridors within the current range that are projected by multiple models to retain suitable climatic conditions and vegetation, have low risk of future mountain pine beetle outbreaks, and to see the least change in relevant climatic variables, may be most likely to support future lynx populations. These climate resilient core habitat areas and corridors may be used as priority areas for the adaptation actions described above.

- Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or improving climatic suitability. Use climatic niche models (Appendix E.3) and vegetation projections (Appendix E.4) to identify potentially stable or improving locations. Use corridor models (Appendix E.1) to identify potential corridors for connecting vulnerable lynx core habitat areas to areas projected to remain climatically suitable or become newly suitable.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[v]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[vi] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

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[v] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[vi] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices E.1-6

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For Canada lynx these materials include:

Appendix E.1. Habitat connectivity models
Appendix E.2. Conceptual model of habitat connectivity
Appendix E.3. Climatic niche models
Appendix E.4. Projected changes in vegetation communities
Appendix E.5. Projected changes in probability of mountain pine beetle survival
Appendix E.6. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. E.2):

i.   **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.

ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).

iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at:
https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e
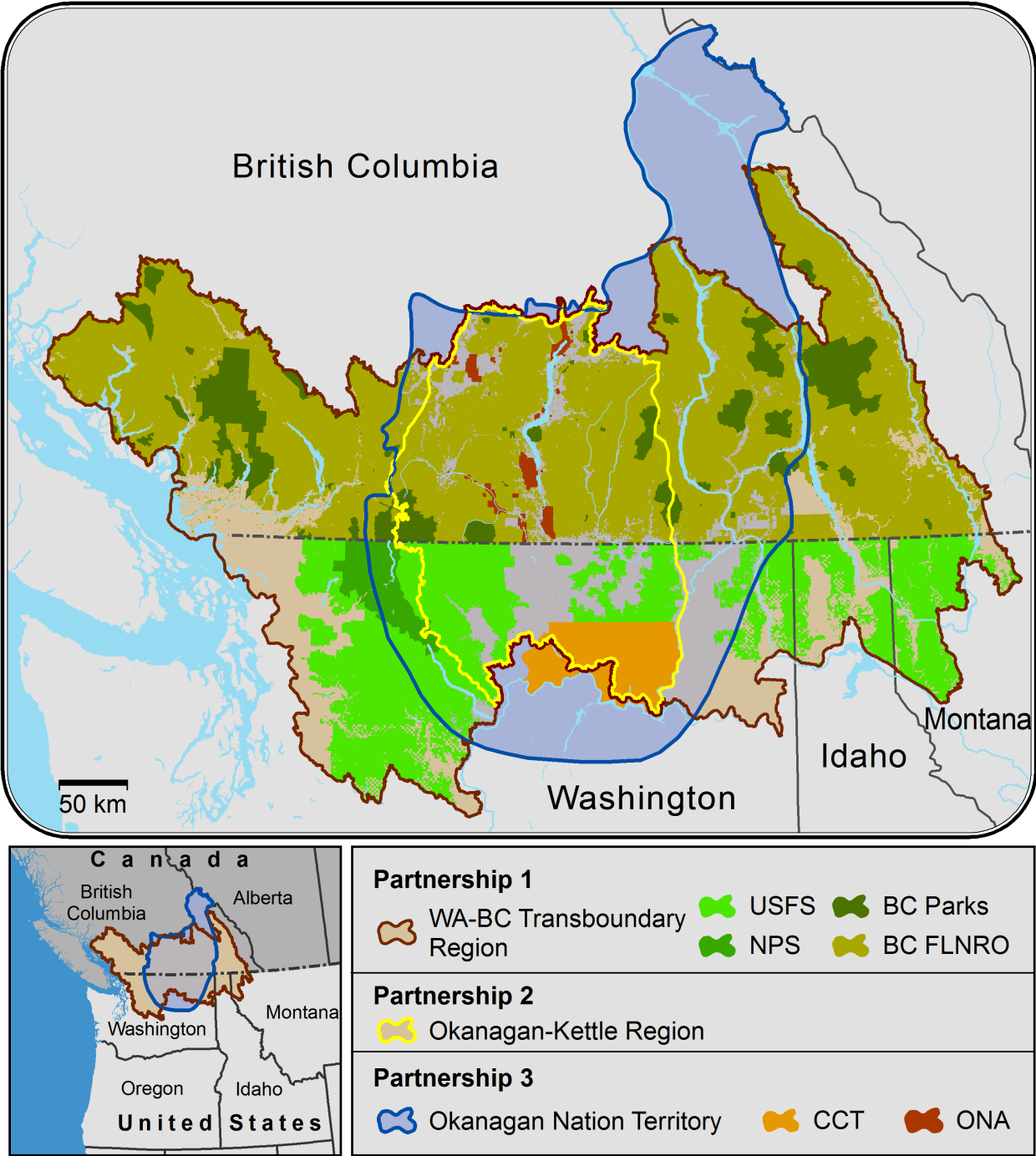
Figure E.2. Project partners and assessment areas.

Appendix E.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vii] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

a) **WHCWG Statewide Analysis: Canada Lynx Corridor Network.**[2] This map shows Habitat Concentration Areas (HCAs, green polygons), which are large, contiguous areas featuring little resistance to species movement; and corridors (glowing yellow areas) connecting HCAs, modeled using least cost corridor analysis. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**[7] This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 $^{\circ}$C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vii] For detailed methodology and data layers see http://www.waconnected.org.

Appendix E.1a. WHCWG Statewide Analysis: Canada Lynx Corridor Network

i) Extent: Okanagan Nation Territory

Canada Lynx Corridor Network
WHWCG Statewide Analysis

Normalized Least-Cost Corridors

Lower cost (0 km NLCC)

Higher cost (100 km NLCC)

Habitat Concentration Area

Kilometers

0   25   50   75
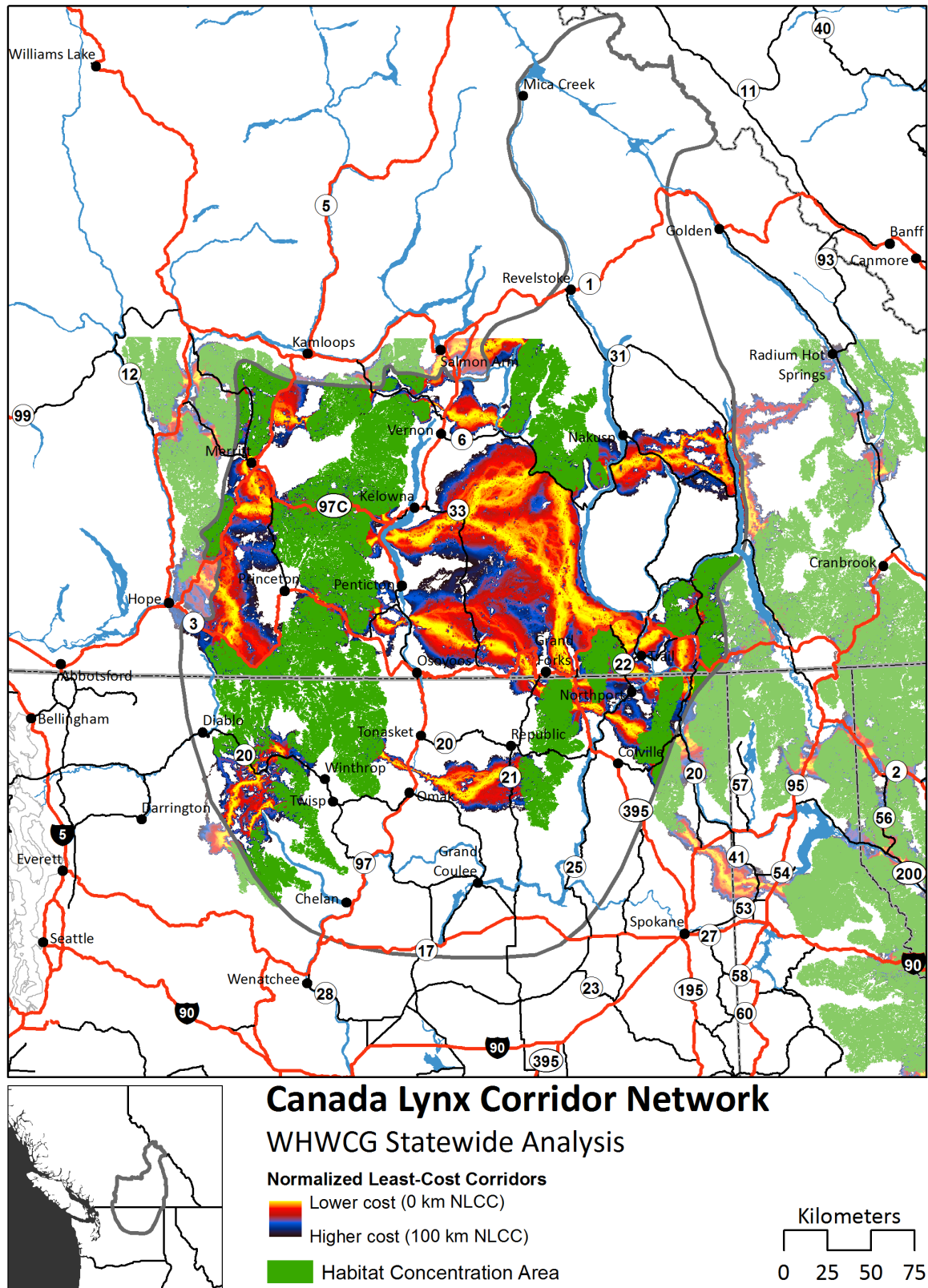
Appendix E.1a. WHCWG Statewide Analysis: Canada Lynx Corridor Network

ii) Extent: Okanagan-Kettle Region

Canada Lynx Corridor Network
WHWCG Statewide Analysis

Normalized Least-Cost Corridors

Lower cost (0 km NLCC)

Higher cost (100 km NLCC)

Habitat Concentration Area

Kilometers
0   15   30   45
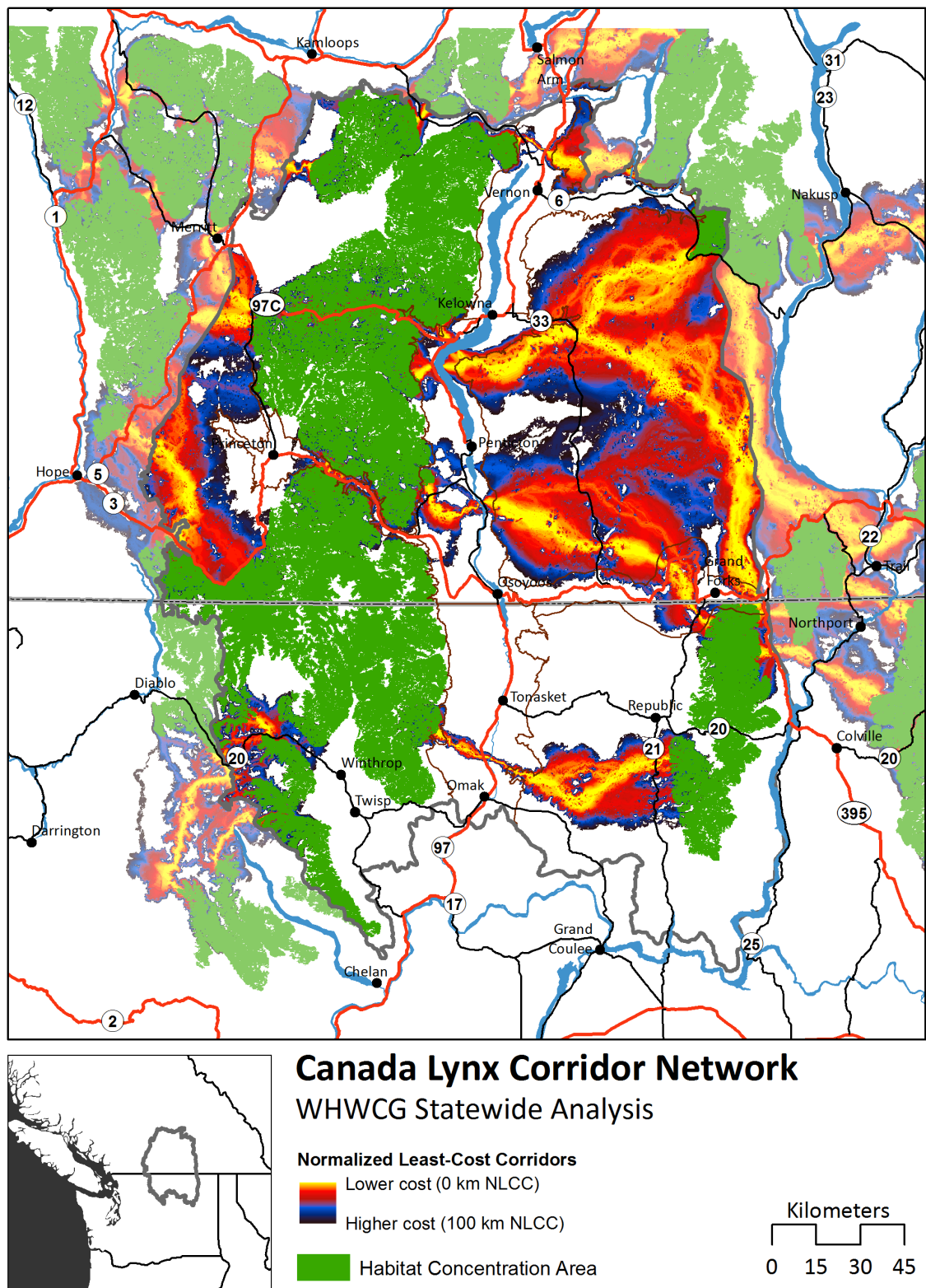
Appendix E.1a. WHCWG Statewide Analysis: Canada Lynx Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region
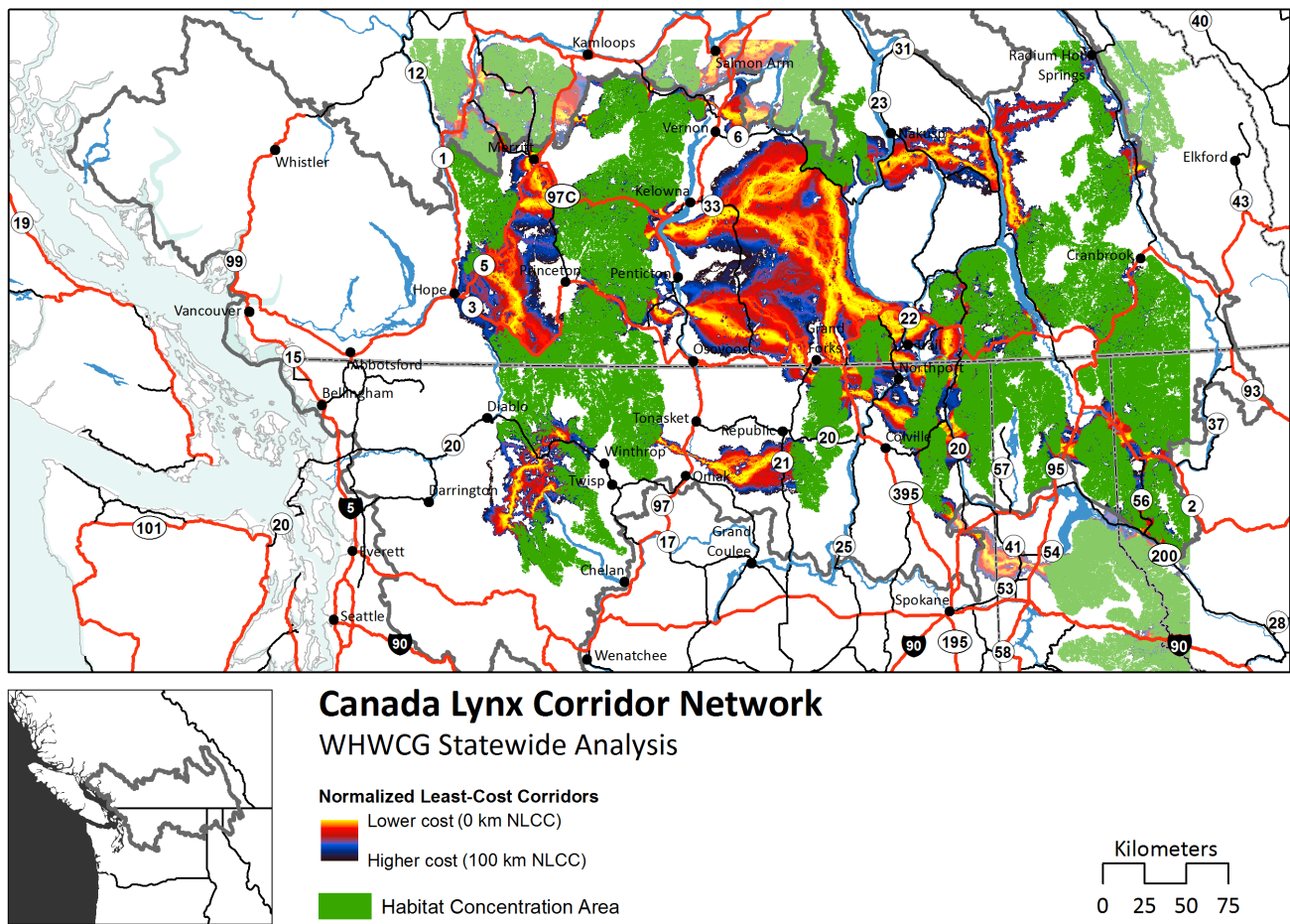
Canada Lynx Corridor Network
WHWCG Statewide Analysis

Normalized Least-Cost Corridors

Lower cost (0 km NLCC)

Higher cost (100 km NLCC)

Habitat Concentration Area

Kilometers

0   25   50   75

Appendix E.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

i) Extent: Okanagan Nation Territory
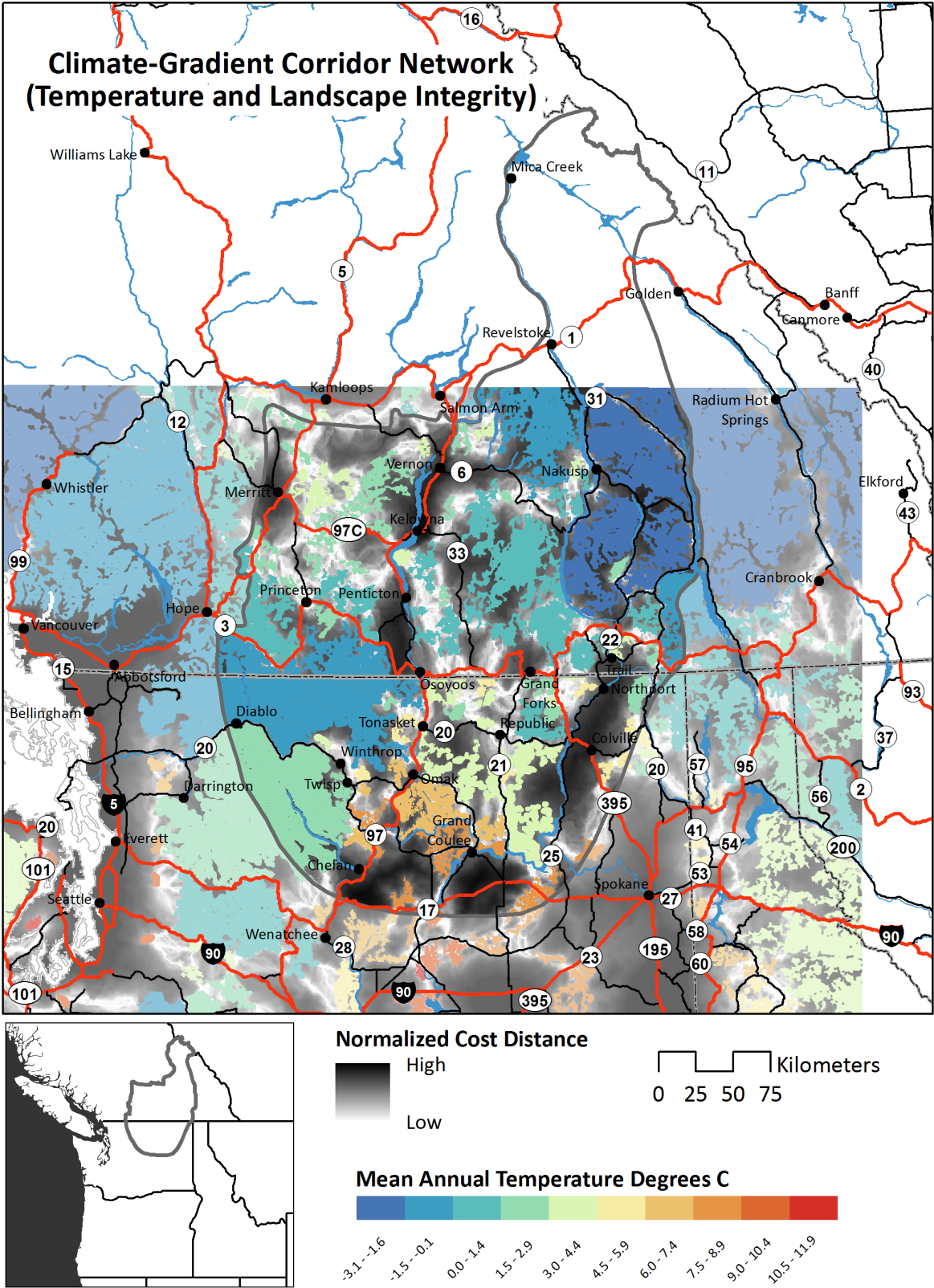
Appendix E.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

ii) Extent: Okanagan-Kettle Region

Climate-Gradient Corridor Network
(Temperature and Landscape Integrity)
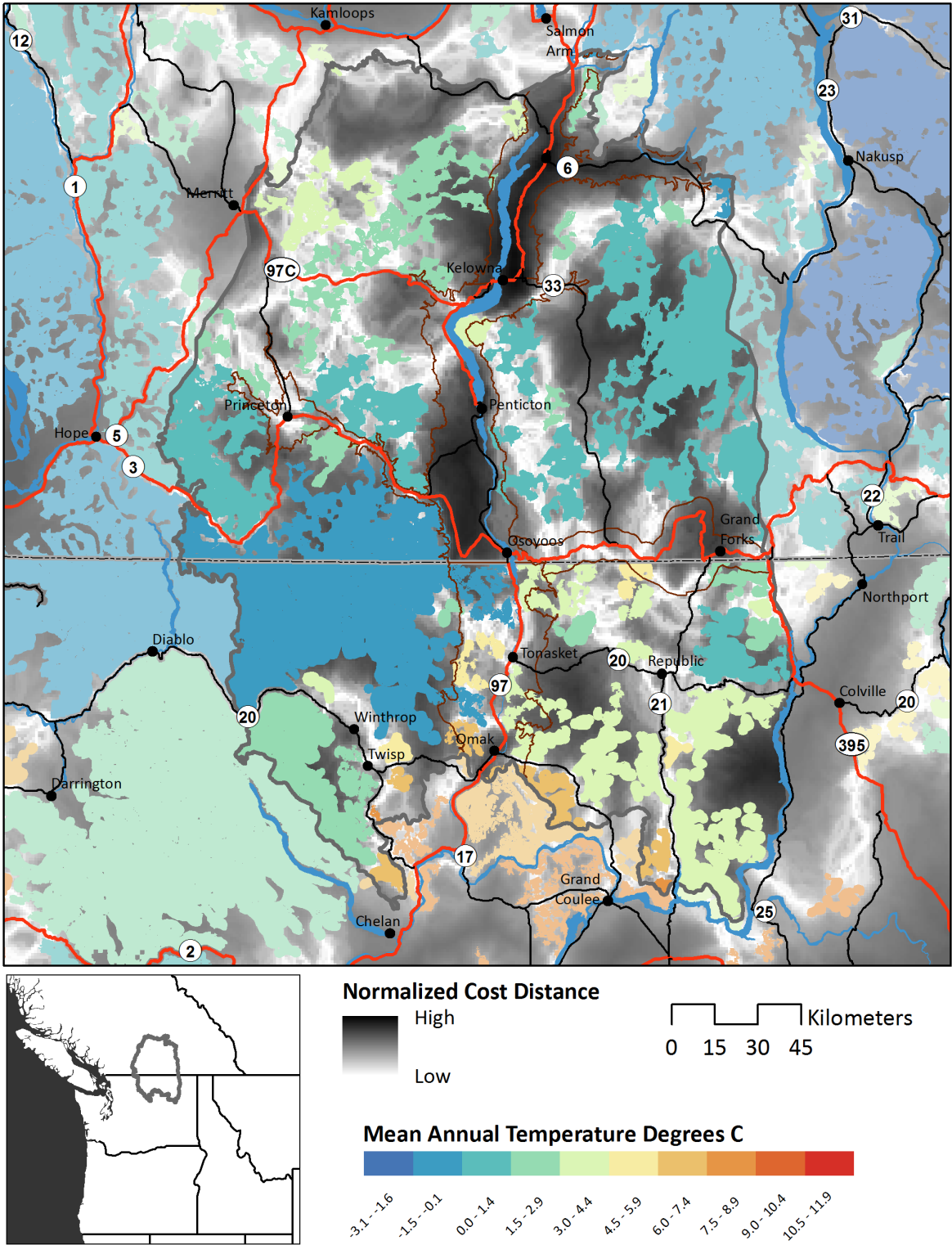
Appendix E.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region
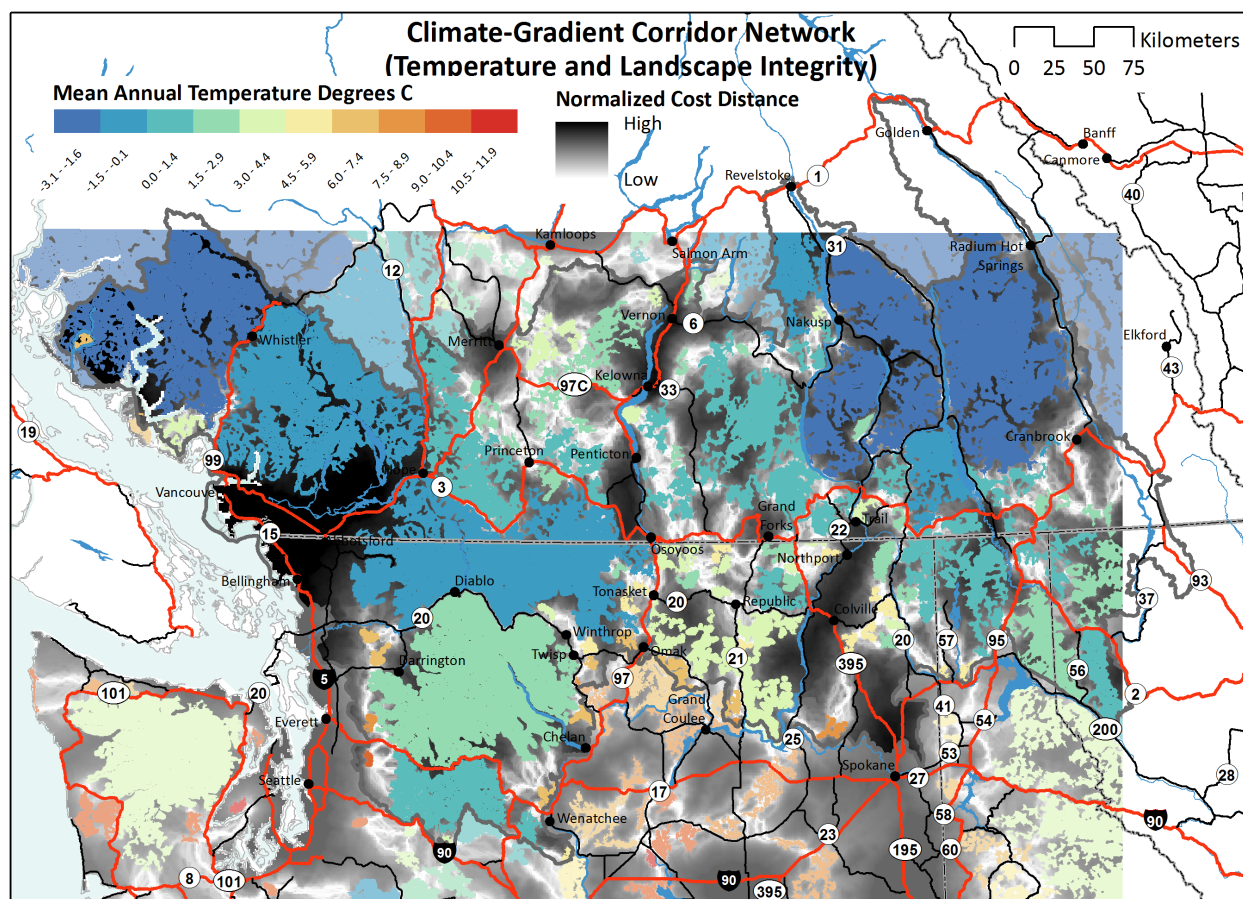
Appendix E.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary Canada lynx habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence Canada lynx habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The Canada lynx conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to Canada lynx habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the Canada lynx conceptual model included:
- Alison Peatt, RPBio, Environmental Planner for South Okanagan-Similkameen Communities
- Westbank First Nation (community member/commercial trapper)

Key references used to create the Canada lynx conceptual model included:

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

Interagency Lynx Biology Team. 2013. Canada lynx conservation assessment and strategy. 3rd edition. USDA Forest Service, USDI Fish and Wildlife Service, USDI Bureau of Land Management, and USDI National Park Service. Forest Service Publication R1-13-19, Missoula, MT. 128 pp.

Buskirk, S. W., L. F. Ruggiero, and C. J. Krebs. 2000a. Habitat fragmentation and interspecific competition: implications for lynx conservation. Pages 83–100 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, and J. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado. Boulder, Colorado, USA.

Gonzalez, P., R. P. Neilson K. S. McKelvey, J. M. Lenihan, and R. J. Drapek. 2007. Potential impacts of climate change on habitat and conservation priority areas for *Lynx canadensis* (Canada Lynx). The Nature Conservancy, Arlington, Virginia, USA.

Hoving, C. L., D. J. Harrison, W. B. Krohn, W. J. Jakubas, and M. A. McCollough. 2004. Canada lynx *Lynx canadensis* habitat and forest succession in northern Maine, USA. *Wildlife Biology* 10:285–294.

Koehler, G. M. 1990. Population and habitat characteristics of lynx and snowshoe hares in north central Washington. *Canadian Journal of Zoology* 68:846–851.

Koehler, G. M., B. T. Maletzke, J. A. von Kienast, K. B. Aubry, R. B. Wielgus, and R. H. Naney. 2008. Habitat fragmentation and the persistence of lynx populations in Washington State. *Journal of Wildlife Management* 72:1518–1524.

Murray, D. L., and S. Boutin. 1991. The influence of snow on lynx and coyote movements: does morphology affect behavior? *Oecologia* 88:463–469.

Squires, J. R., N. J. Decesare, J. A. Kolbe, and L. F. Ruggiero. 2010. Seasonal resource selection of Canada lynx in managed forests of the northern Rocky Mountains. *Journal of Wildlife Management* 74:1648–1660.

Ward, R. M. P., and C. J. Krebs. 1985. Behavioral responses of lynx to declining snowshoe hare abundance. *Canadian Journal of Zoology* 63:2817–2824.

Appendix E.2. Conceptual model of Canada lynx habitat connectivity
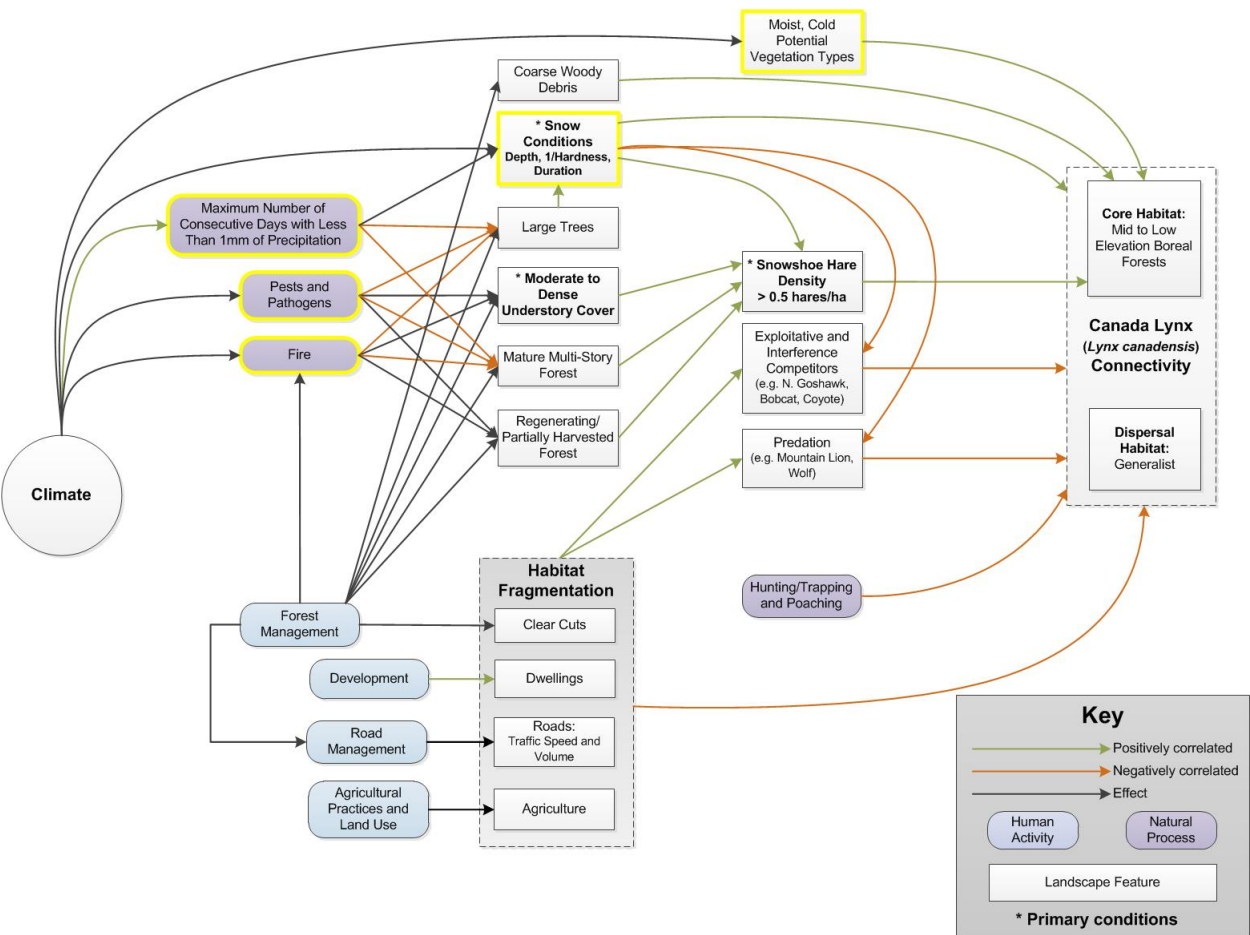
Appendix E.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[viii] Both models use the A2 (high) emissions scenario.[ix] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[x]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

[viii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[ix] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[x] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix E.3. Canada Lynx Climatic Niche Model
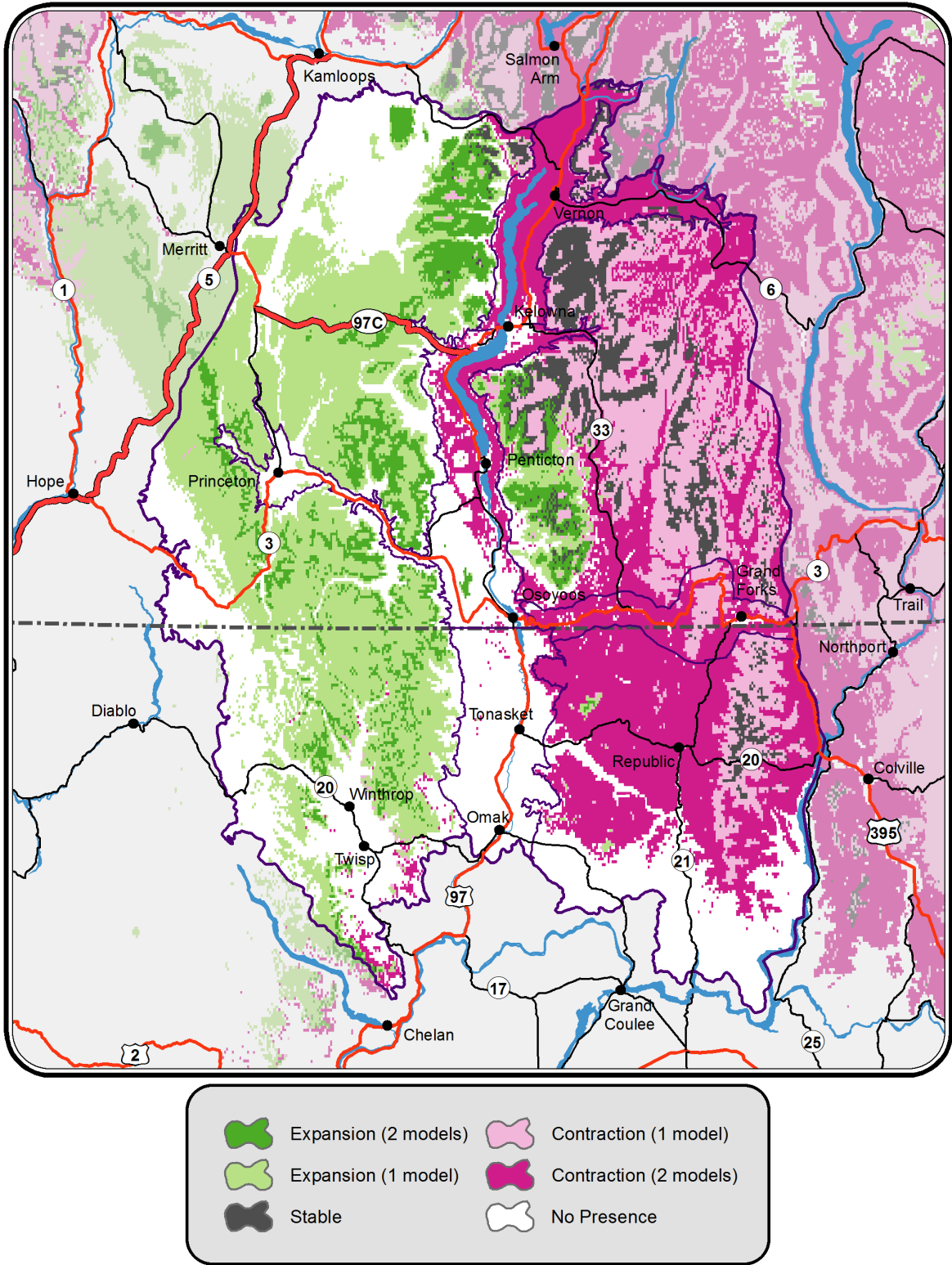
i) Extent: Okanagan Nation Territory

Canadian Lynx-*Lynx canadensis*

Legend:
- Expansion (2 models)
- Expansion (1 model)
- Stable
- Contraction (1 model)
- Contraction (2 models)
- No Presence
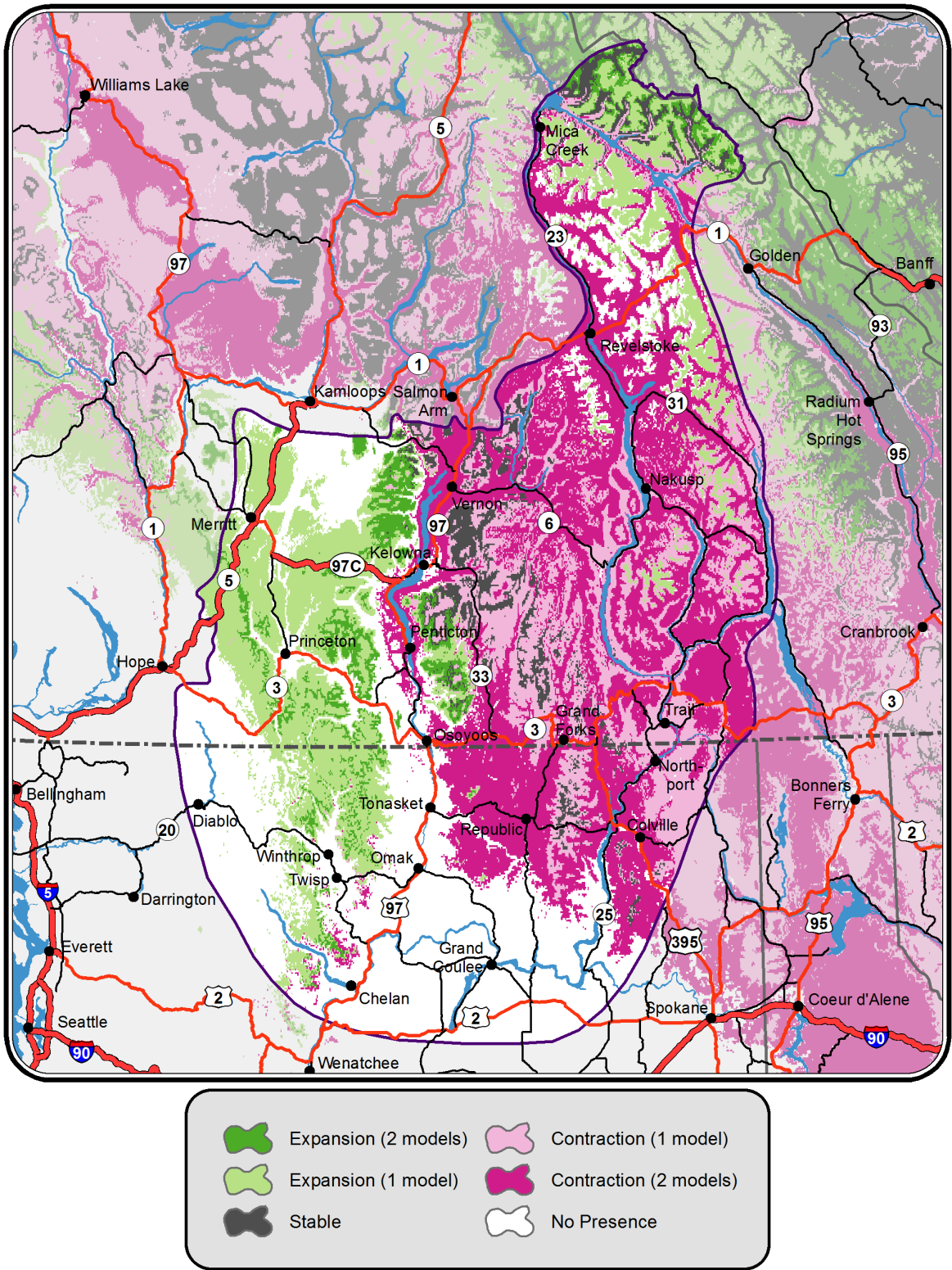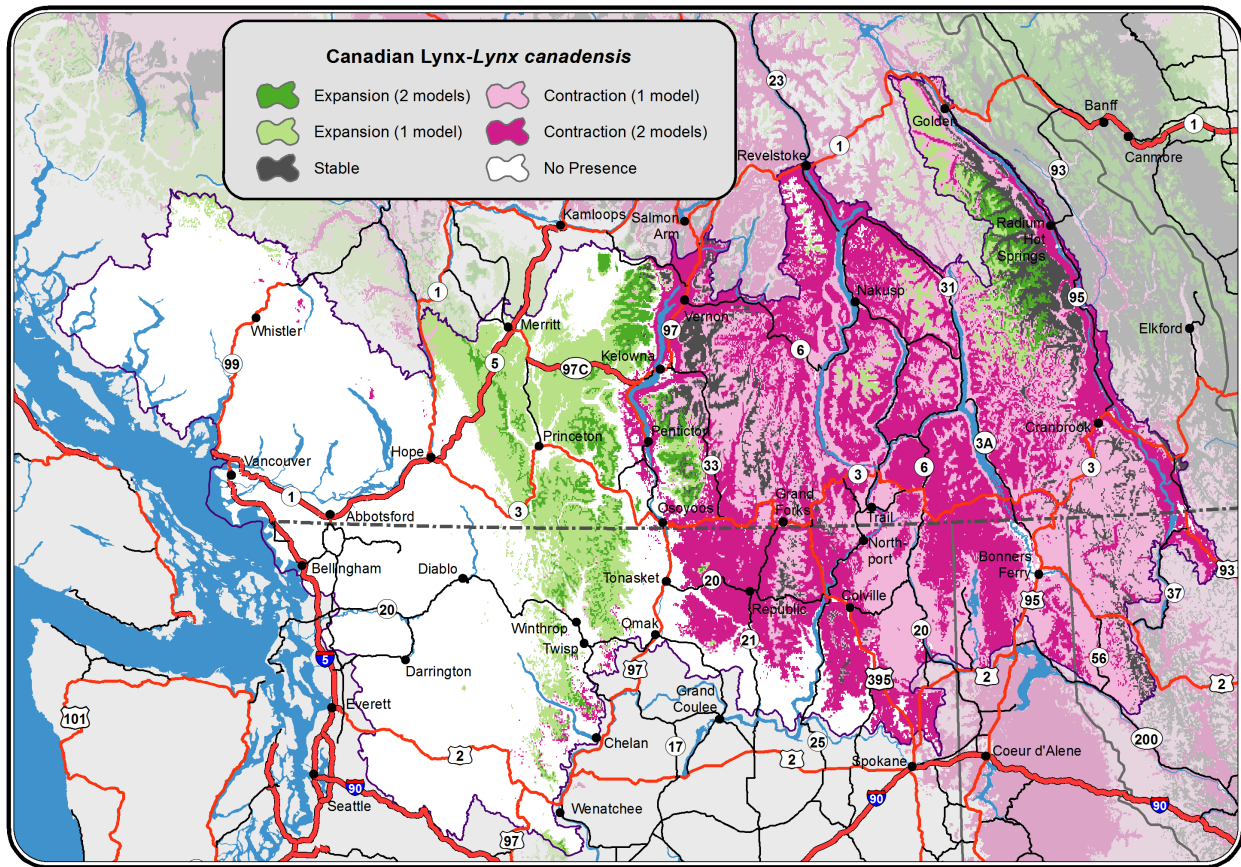
Appendix E.3. Canada Lynx Climatic Niche Model

ii) Extent: Okanagan-Kettle Region

Canadian Lynx-*Lynx canadensis*

Appendix E.3. Canada Lynx Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region

Appendix E.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[xi] Both models also use the A2 (high) emissions scenario.[xii]

a) **Biome Climatic Niche Vegetation Model.[xiii]** This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.[xiv]** This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[xi] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[xii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xiii] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xiv] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.
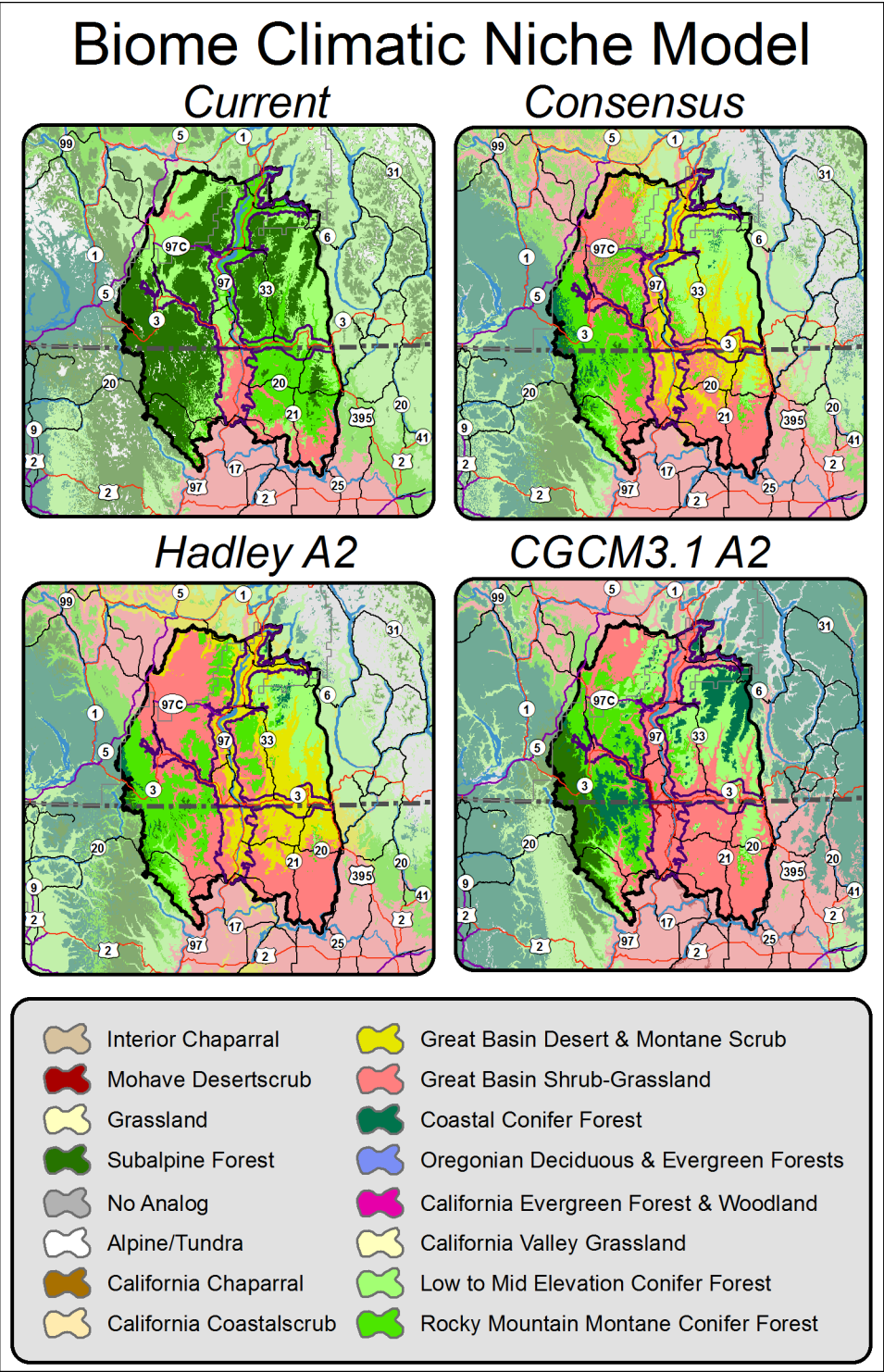
Appendix E.4a. Biome Climatic Niche Model
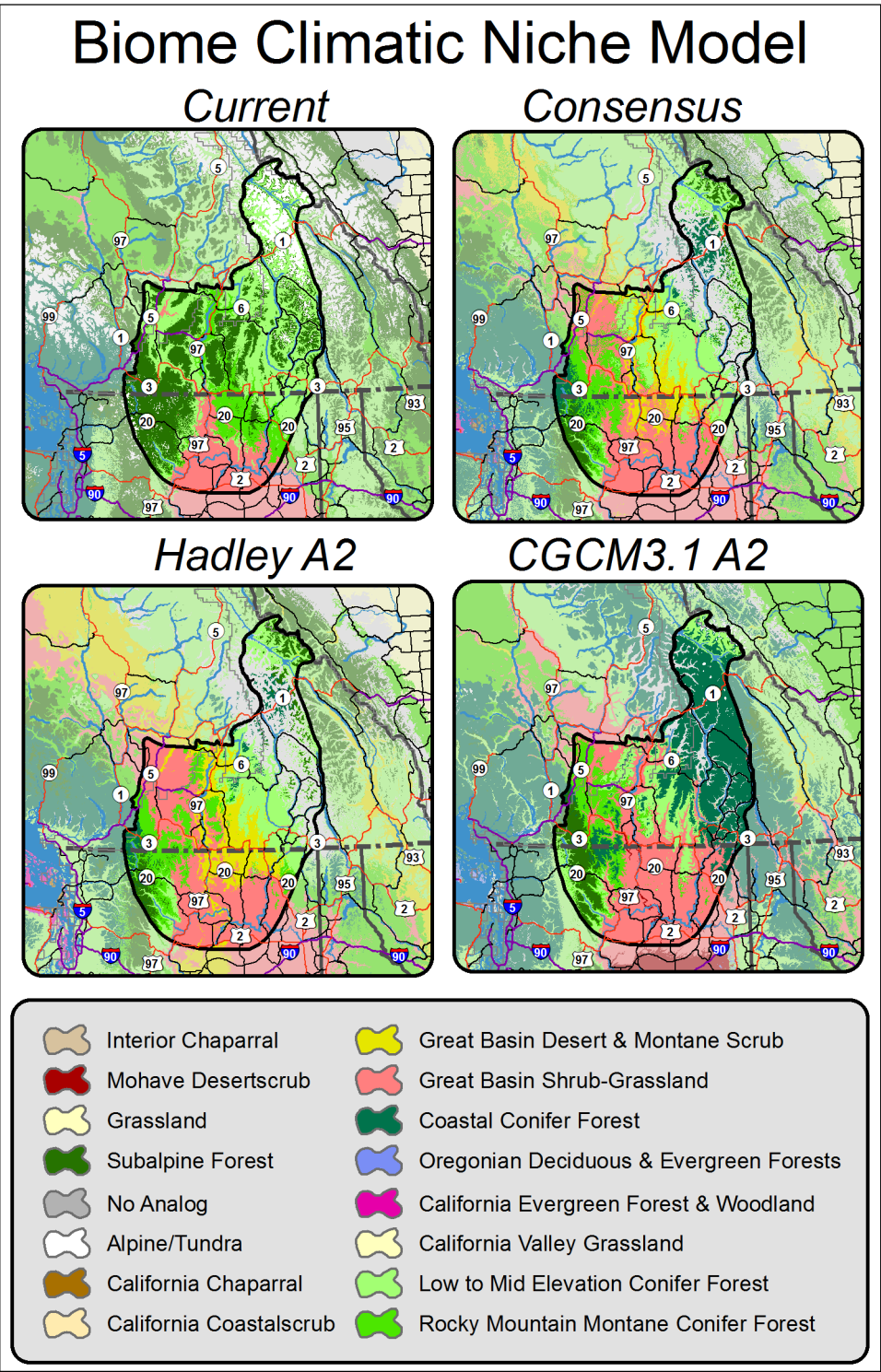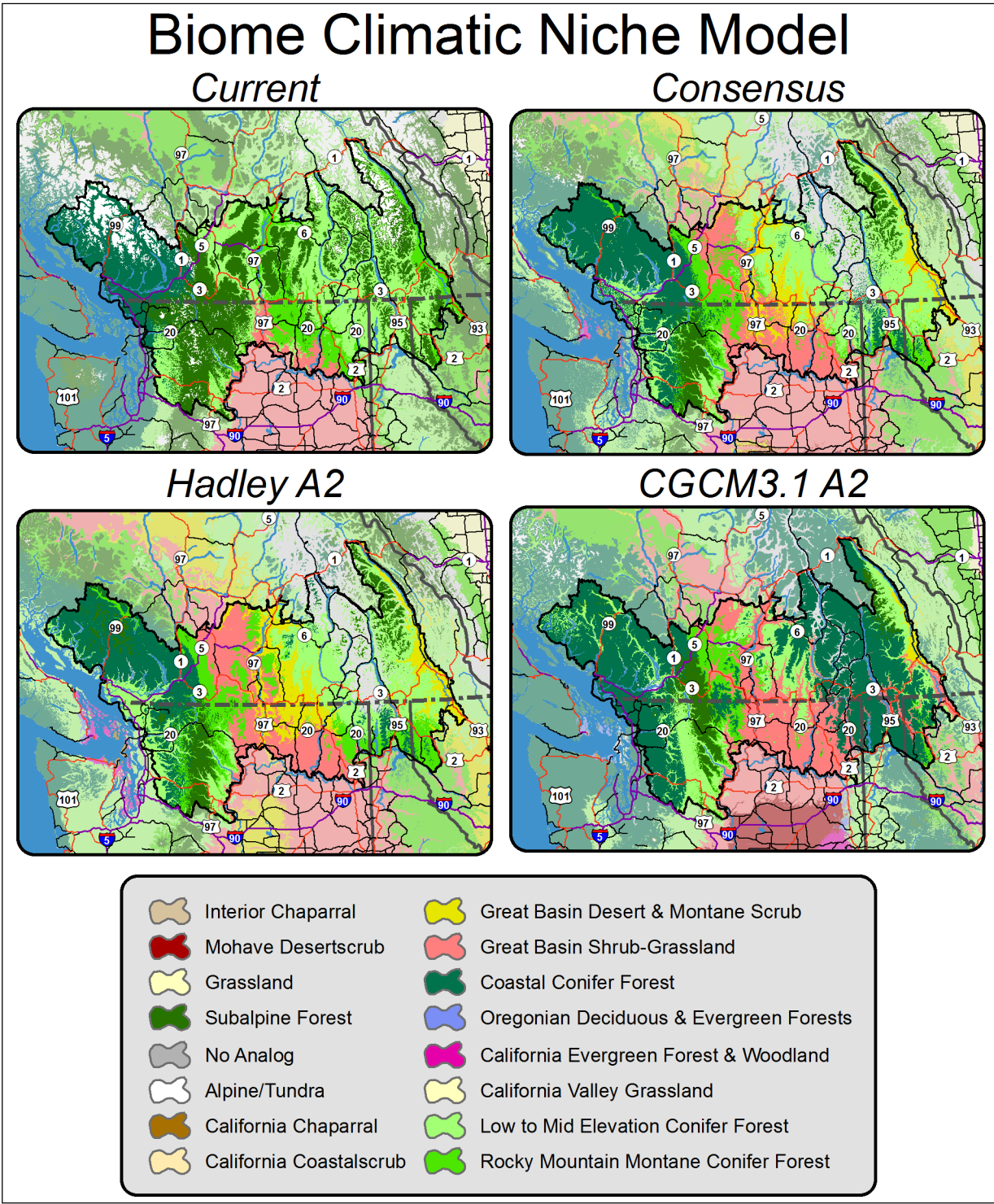
i) Extent: Okanagan Nation Territory

Appendix E.4a. Biome Climatic Niche Model
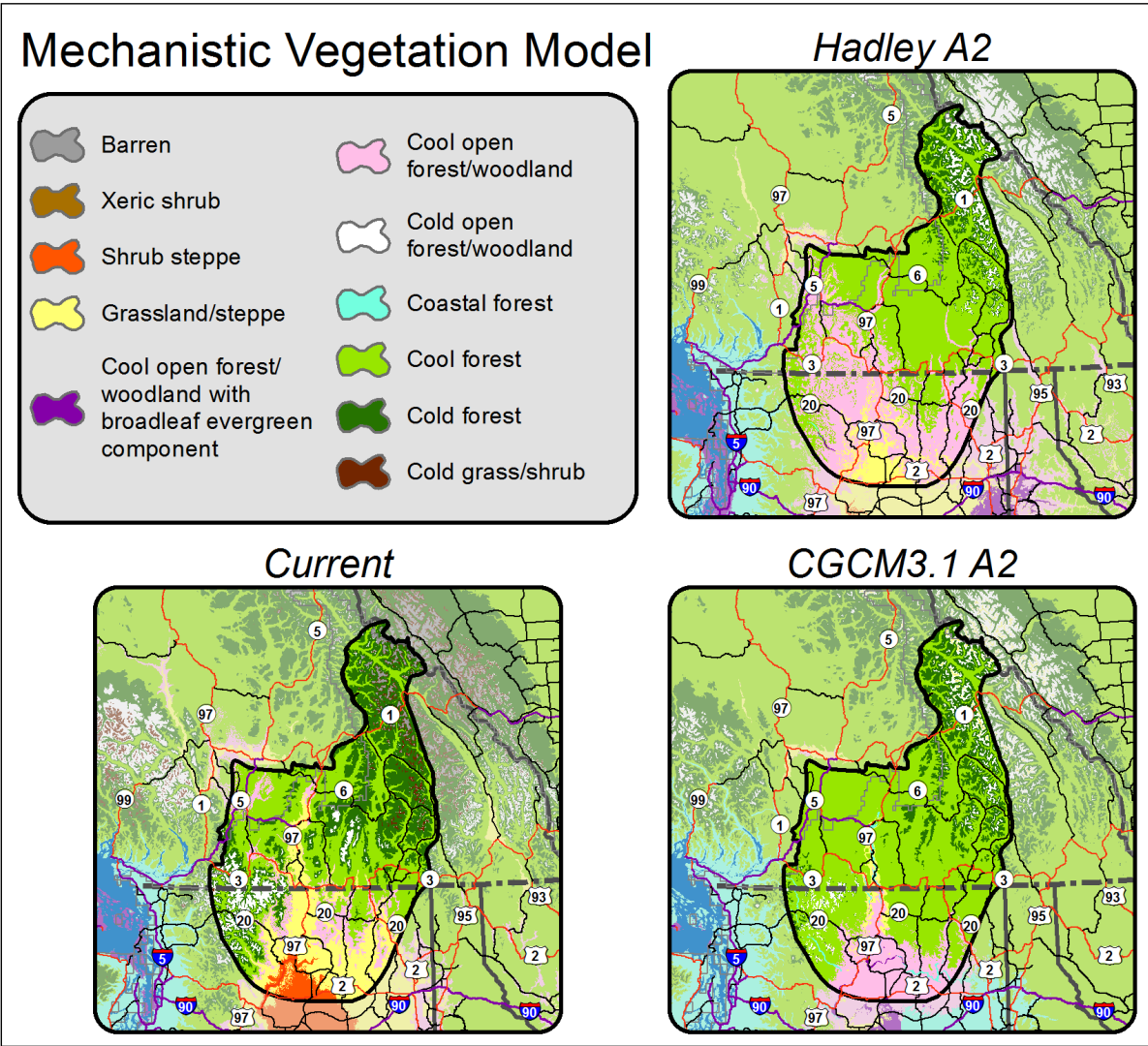
ii) Extent: Okanagan-Kettle Region

Appendix E.4a. Biome Climatic Niche Model
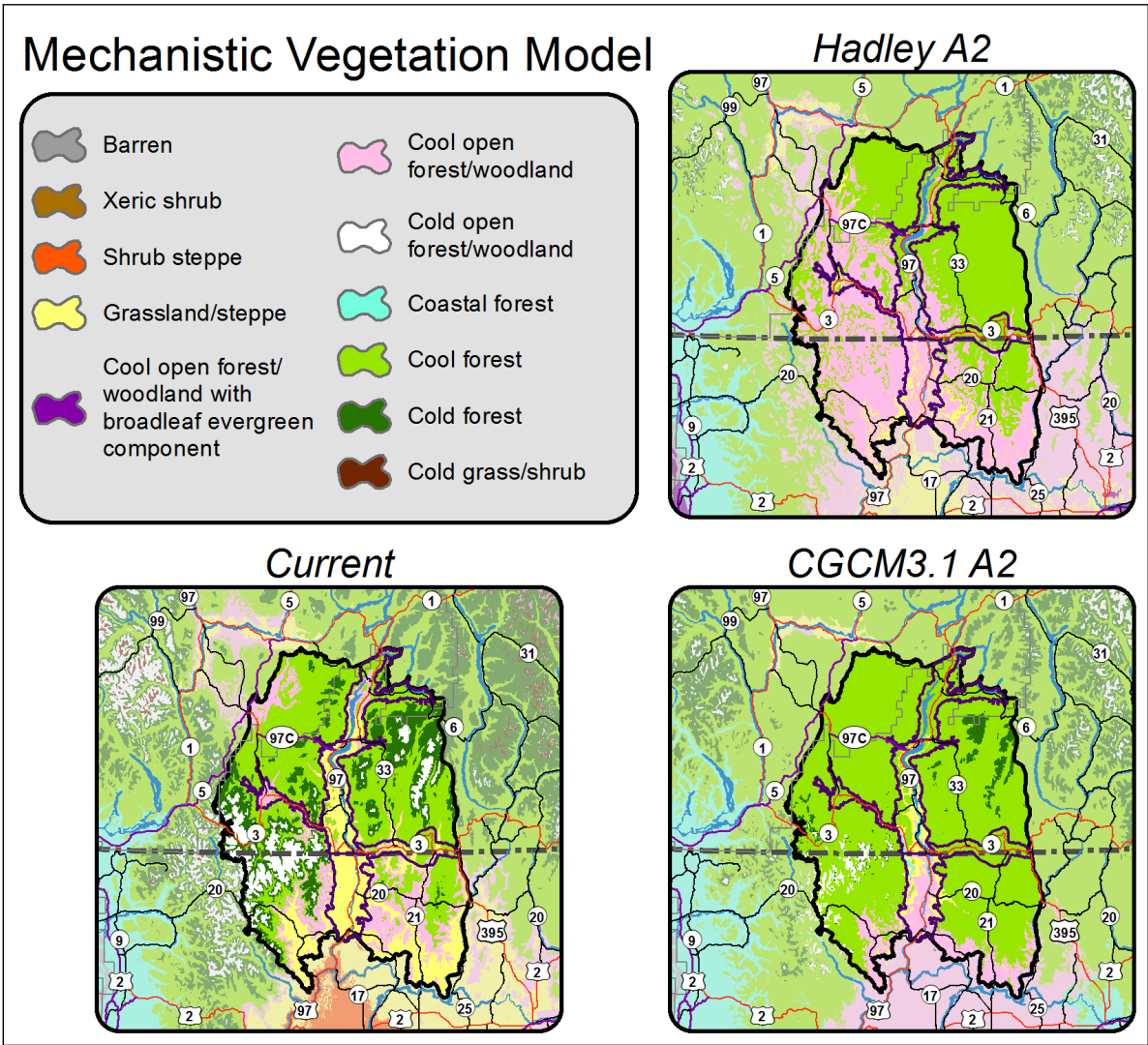
iii) Extent: Washington-British Columbia Transboundary Region

Biome Climatic Niche Model

Current *Consensus*

Hadley A2 *CGCM3.1 A2*

Legend:
- Interior Chaparral
- Mohave Desertscrub
- Grassland
- Subalpine Forest
- No Analog
- Alpine/Tundra
- California Chaparral
- California Coastalscrub
- Great Basin Desert & Montane Scrub
- Great Basin Shrub-Grassland
- Coastal Conifer Forest
- Oregonian Deciduous & Evergreen Forests
- California Evergreen Forest & Woodland
- California Valley Grassland
- Low to Mid Elevation Conifer Forest
- Rocky Mountain Montane Conifer Forest

Appendix E.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory

Appendix E.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region

Appendix E.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region
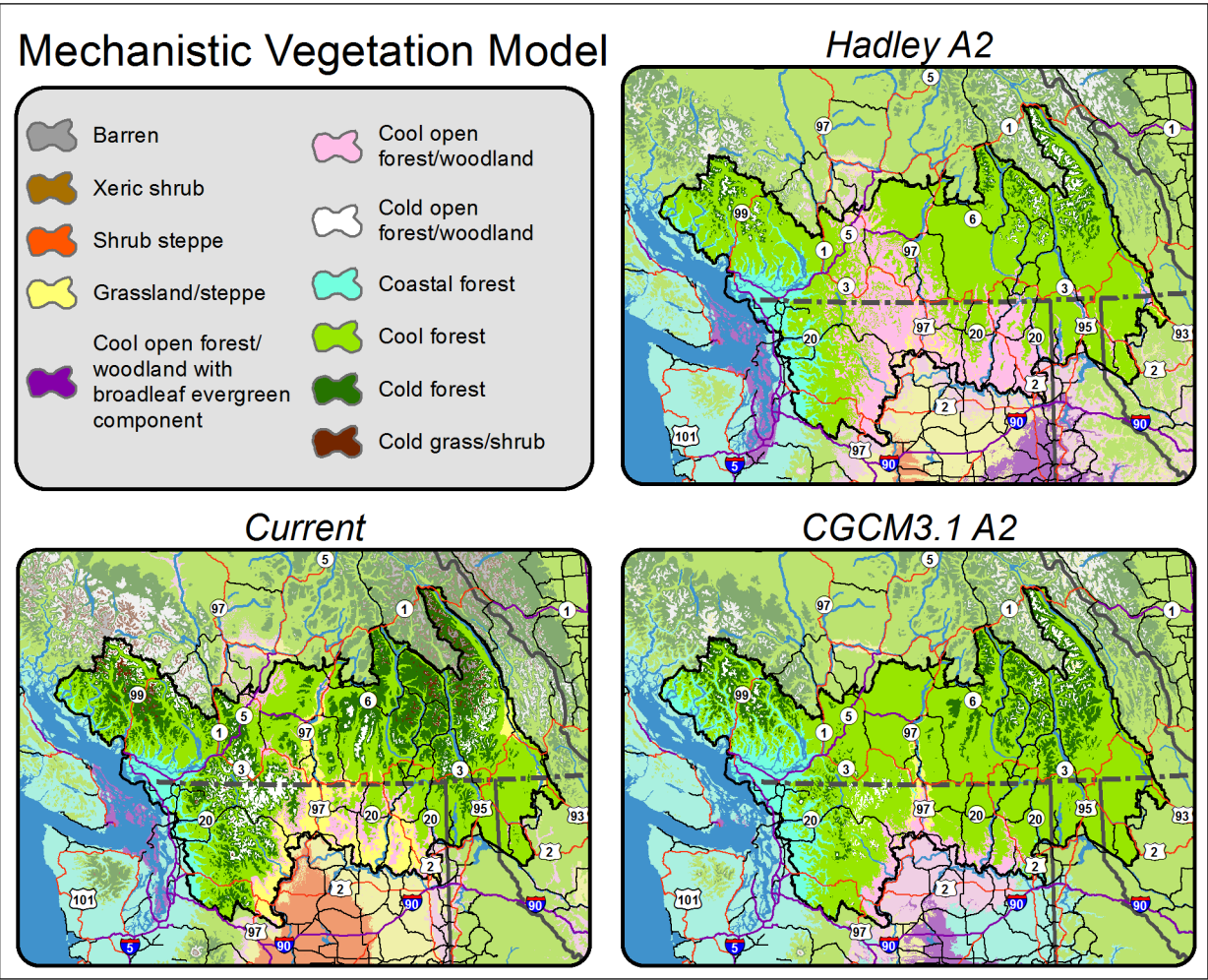
Appendix E.5. Projected Changes in Probability of Mountain Pine Beetle Survival

Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are projected to decrease in the future.[xv,xvi]

[xv] Mote, P.W., Snover, A.K., Capalbo, S.M., Eigenbrode, S., Glick, P., Littell, J.S., Raymondi, R., Reeder, S. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.

[xvi] Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance, spring precipitation, and seasonal heat accumulation. [xv] Projections are only available for the United States.

Appendix E.5. Probability of Mountain Pine Beetle Survival

i) Extent: Okanagan Nation Territory

Change in probability of mountain pine beetle survival
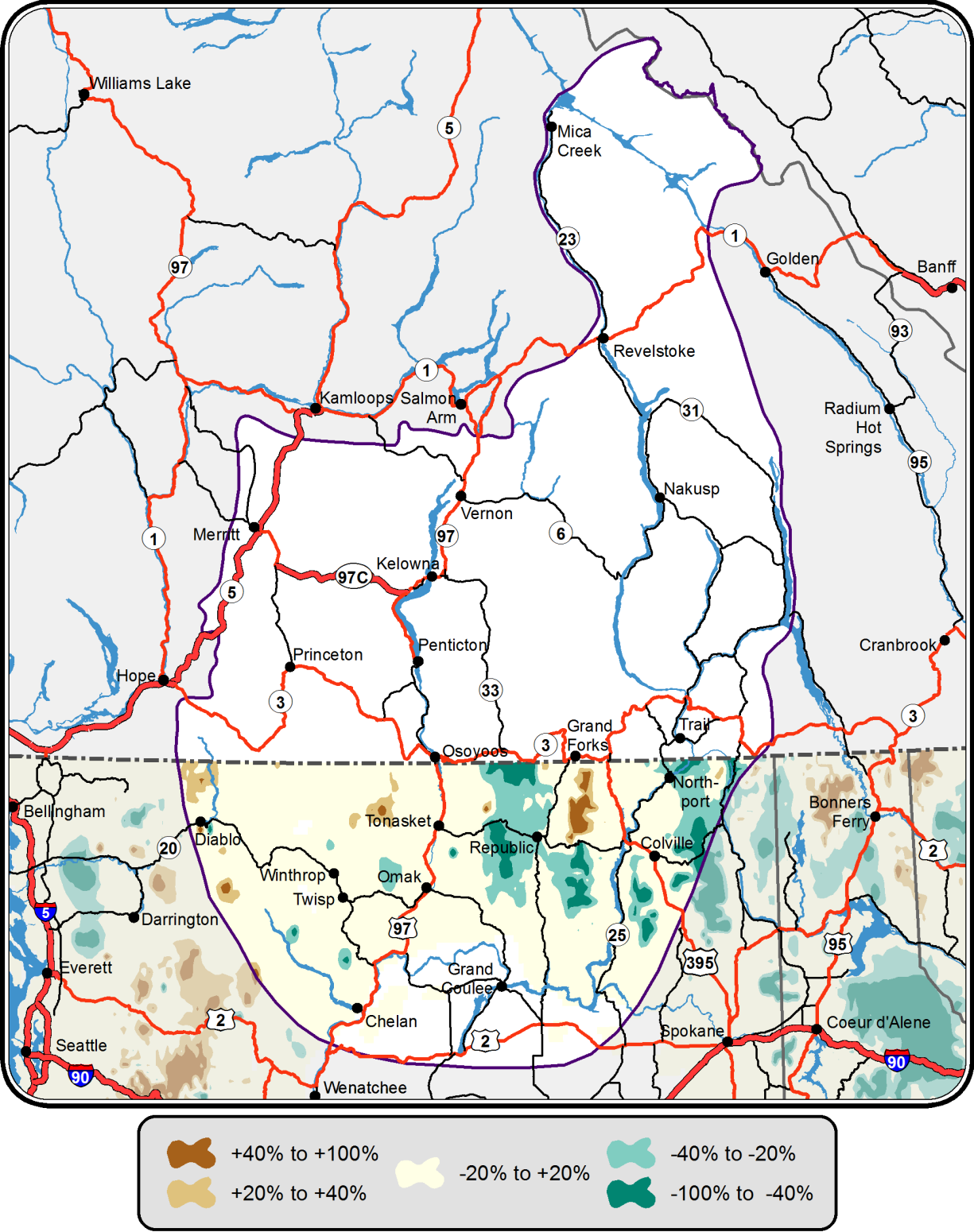
Appendix E.5. Probability of Mountain Pine Beetle Survival

ii) Extent: Okanagan-Kettle Region

Change in probability of mountain pine beetle survival
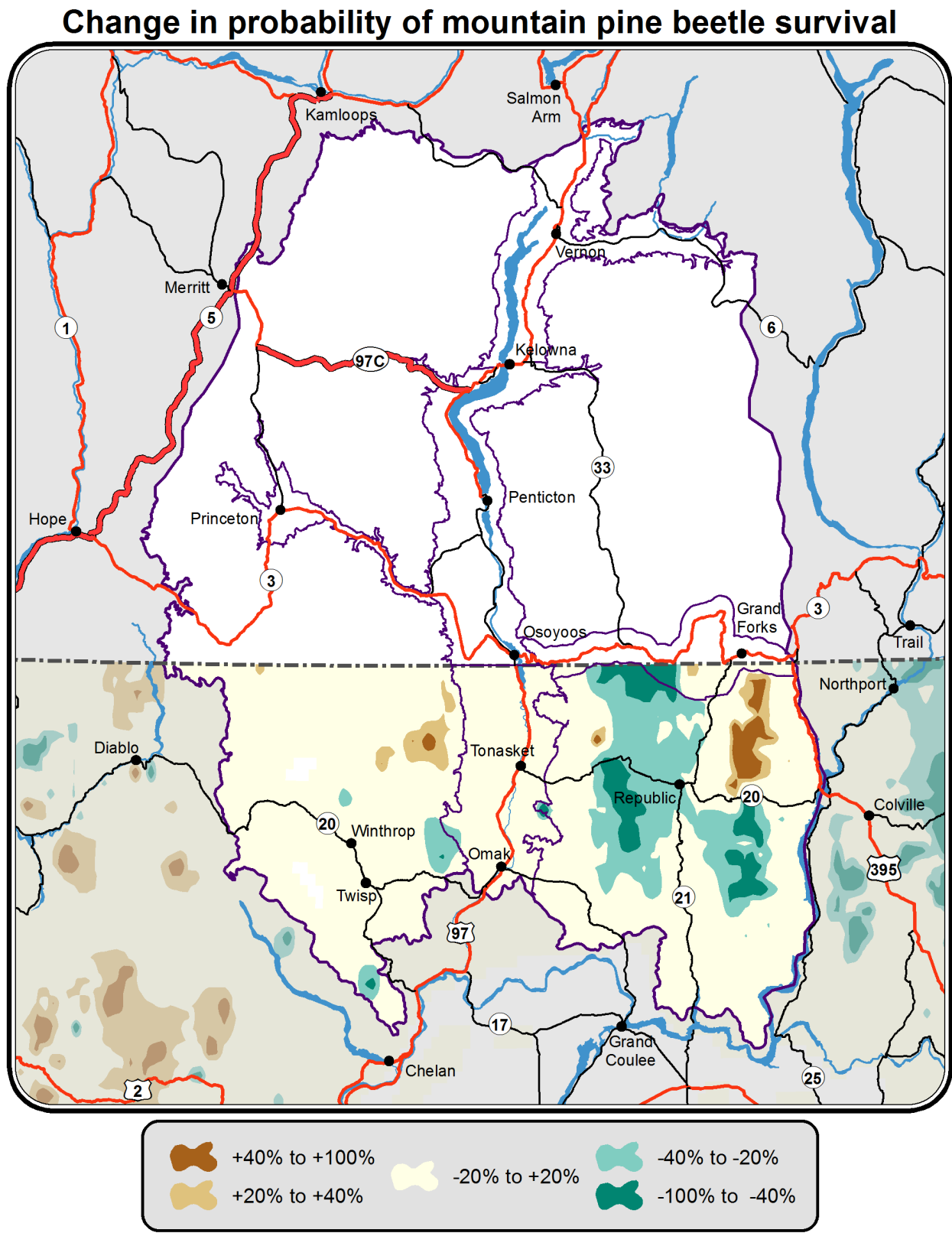
Appendix E.5. Probability of Mountain Pine Beetle Survival

iii) Extent: Washington-British Columbia Transboundary Region
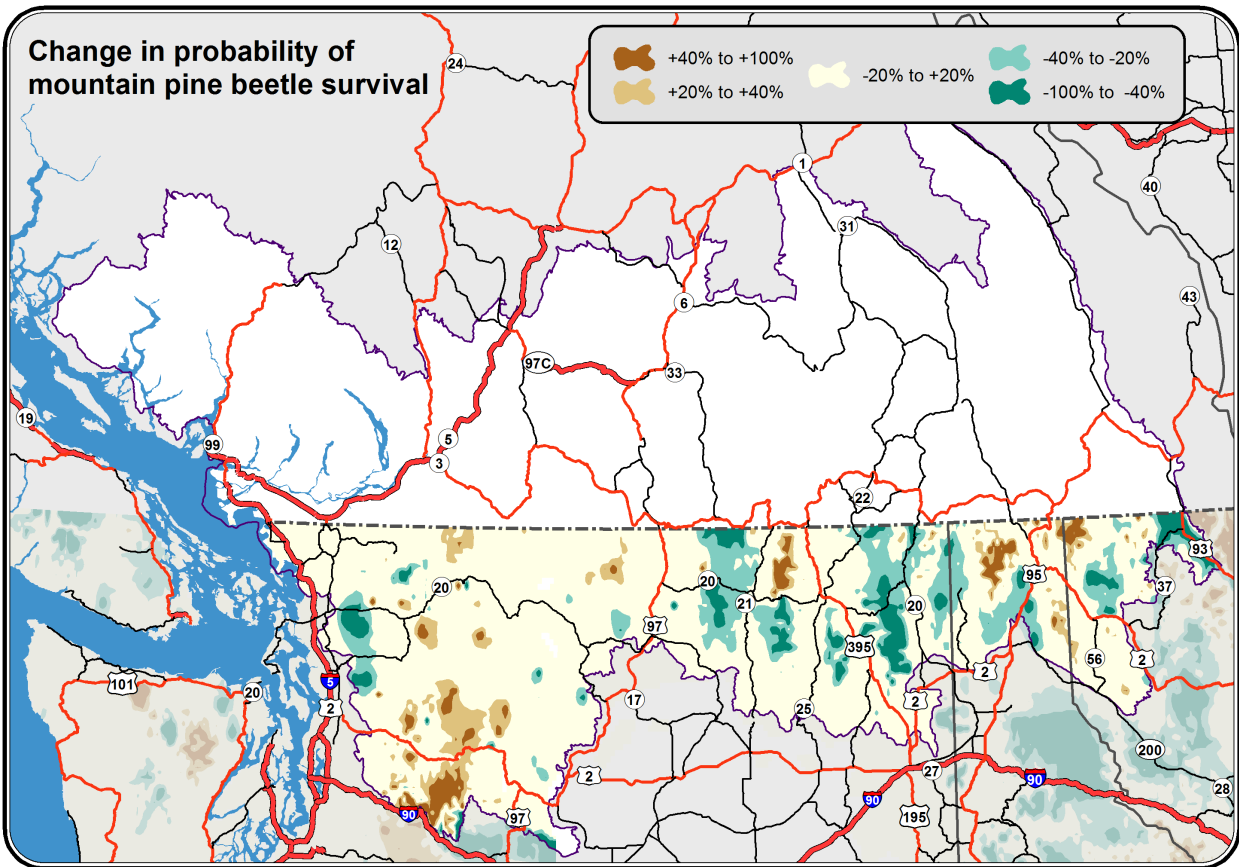
Appendix E.6. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on Canada lynx connectivity.[xvii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[8] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Length of Snow Season.** This map shows the projected change in the length of the snow season, defined as the number of days between the first and last days of the season with at least 10% of annual maximum snow water equivalent. Projected changes in snow season length are depicted by the yellow to red shading.

c) **Percentage of Winter Precipitation Captured in April 1st Snowpack.** This map shows the projected percentage of winter (October-March) precipitation that is retained in April 1st snowpack. The map classifies the results in three categories: rain dominant (green: <10%), mixed-rain-and-snow (orange: 10-40%), and snow dominant (blue: >40%).

d) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xviii] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

e) **Dry Spell Duration.** This map shows the projected change, in percent, in the maximum number of consecutive days with less than 1 mm of precipitation. Projected change in dry spell duration is depicted by the brown to green shading.

[xvii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

[xviii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.
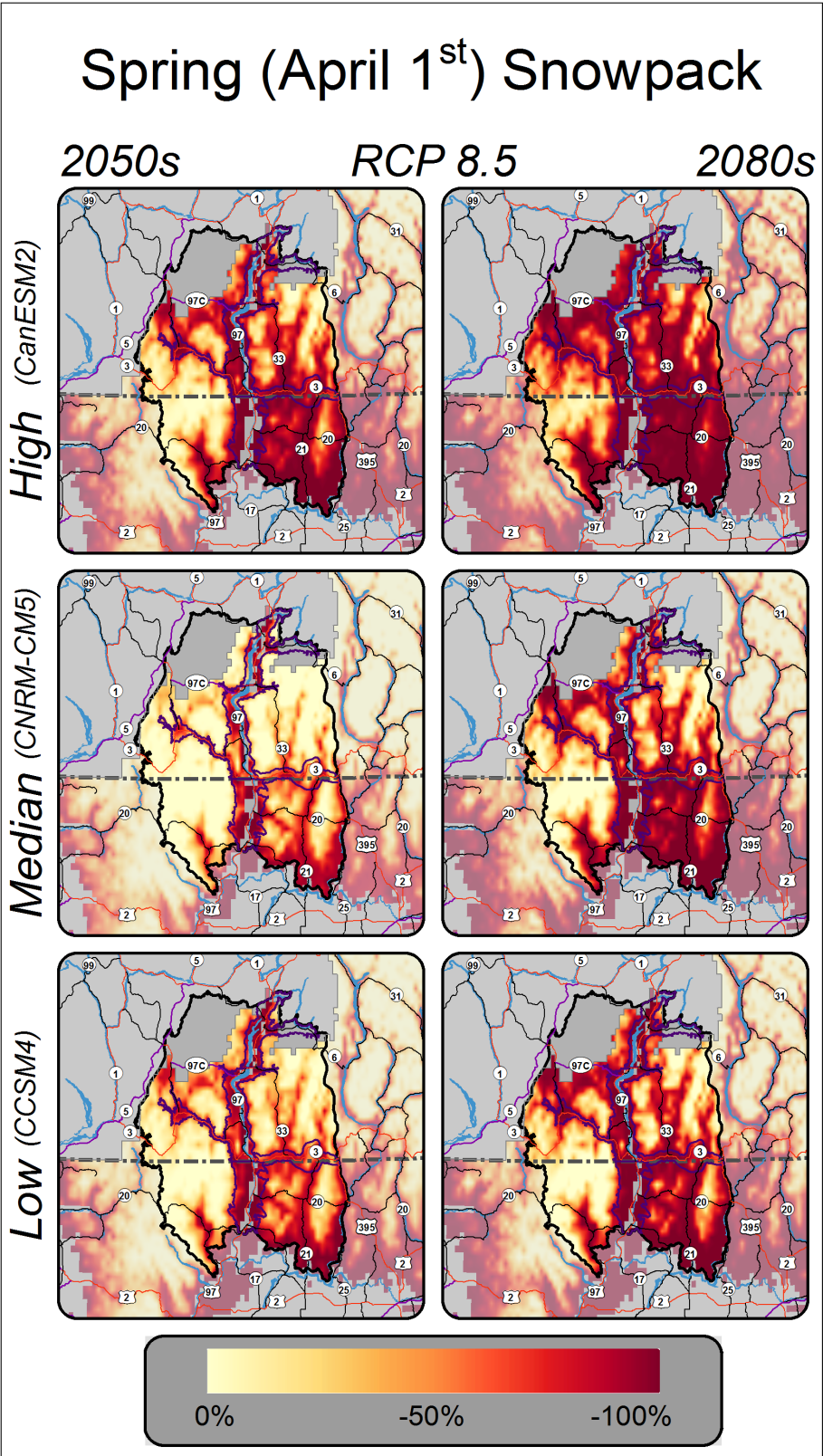
Appendix E.6a. Spring (April 1ˢᵗ) Snowpack

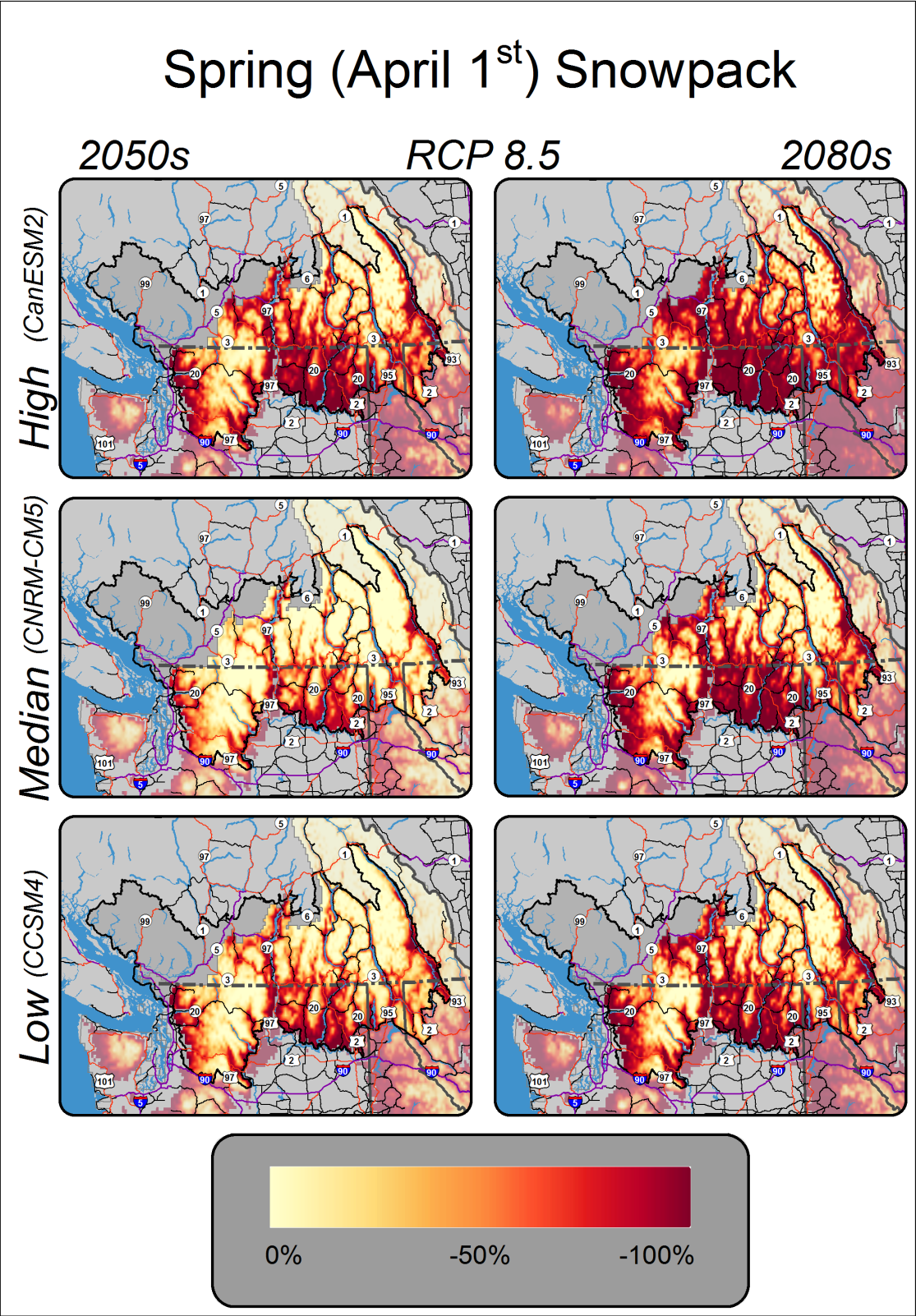i) Extent: Okanagan Nation Territory
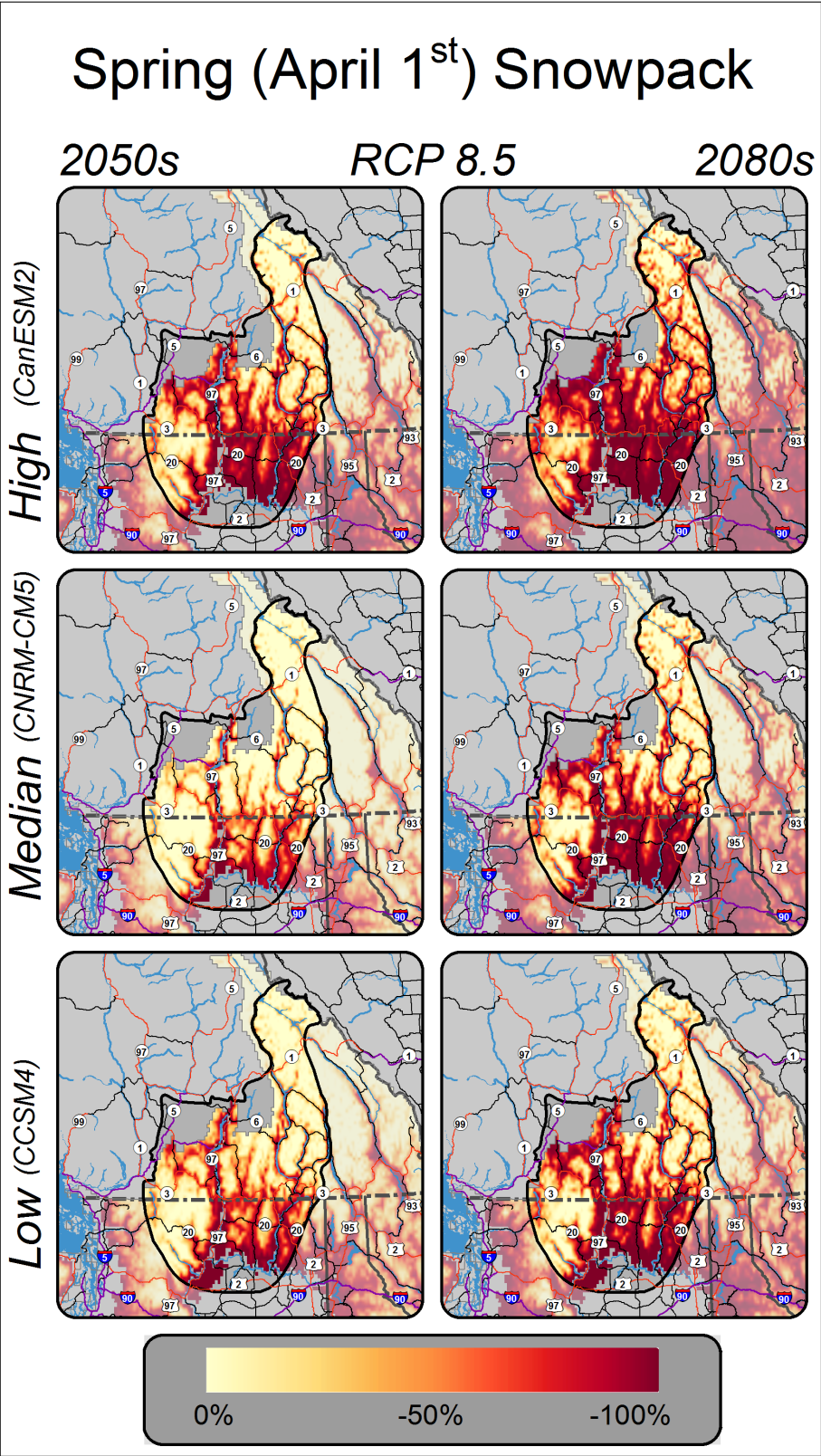
Appendix E.6a. Spring (April 1st) Snowpack
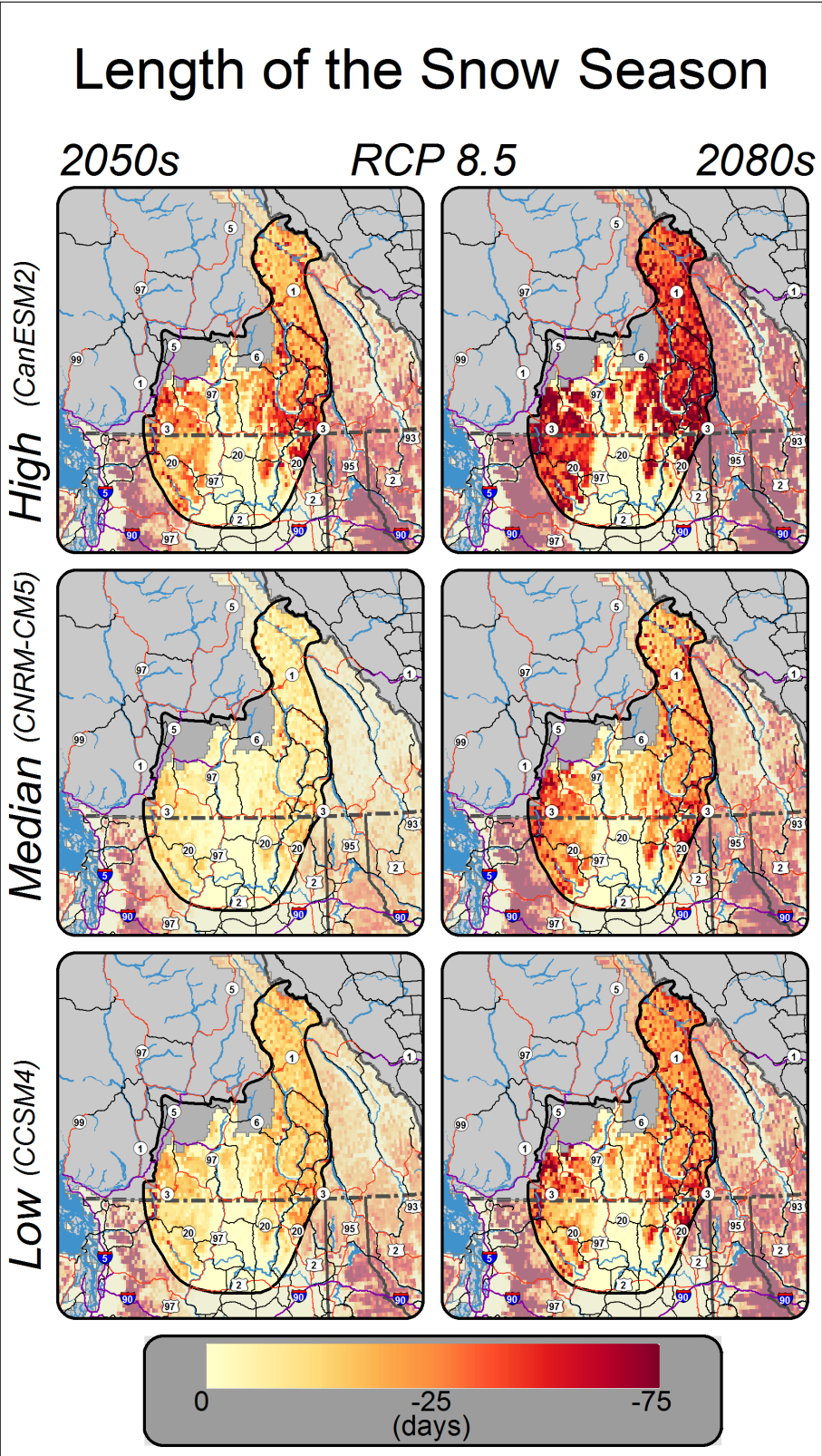
ii) Extent: Okanagan-Kettle Region

Appendix E.6a. Spring (April 1st) Snowpack

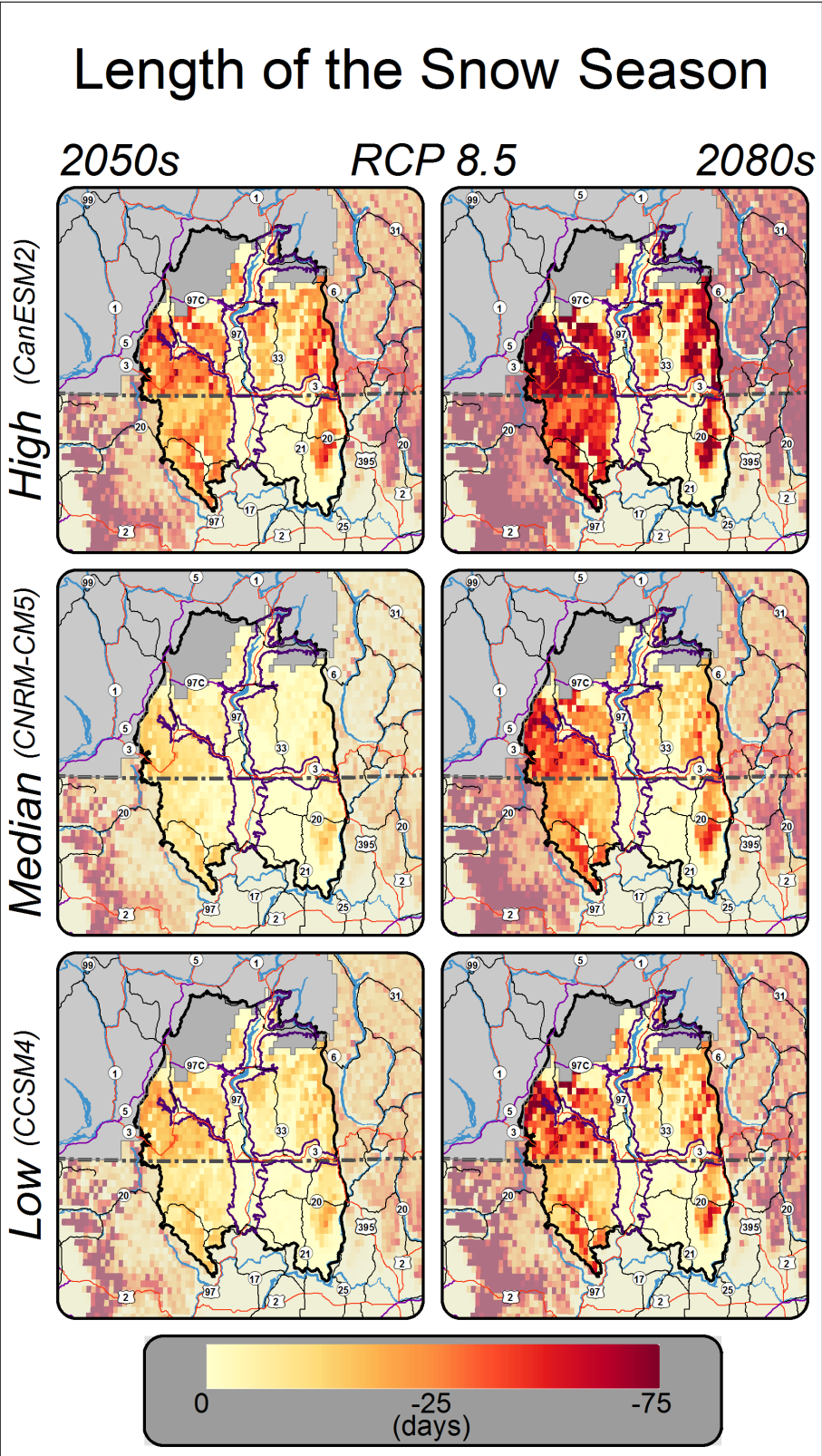iii) Extent: Washington-British Columbia Transboundary Region

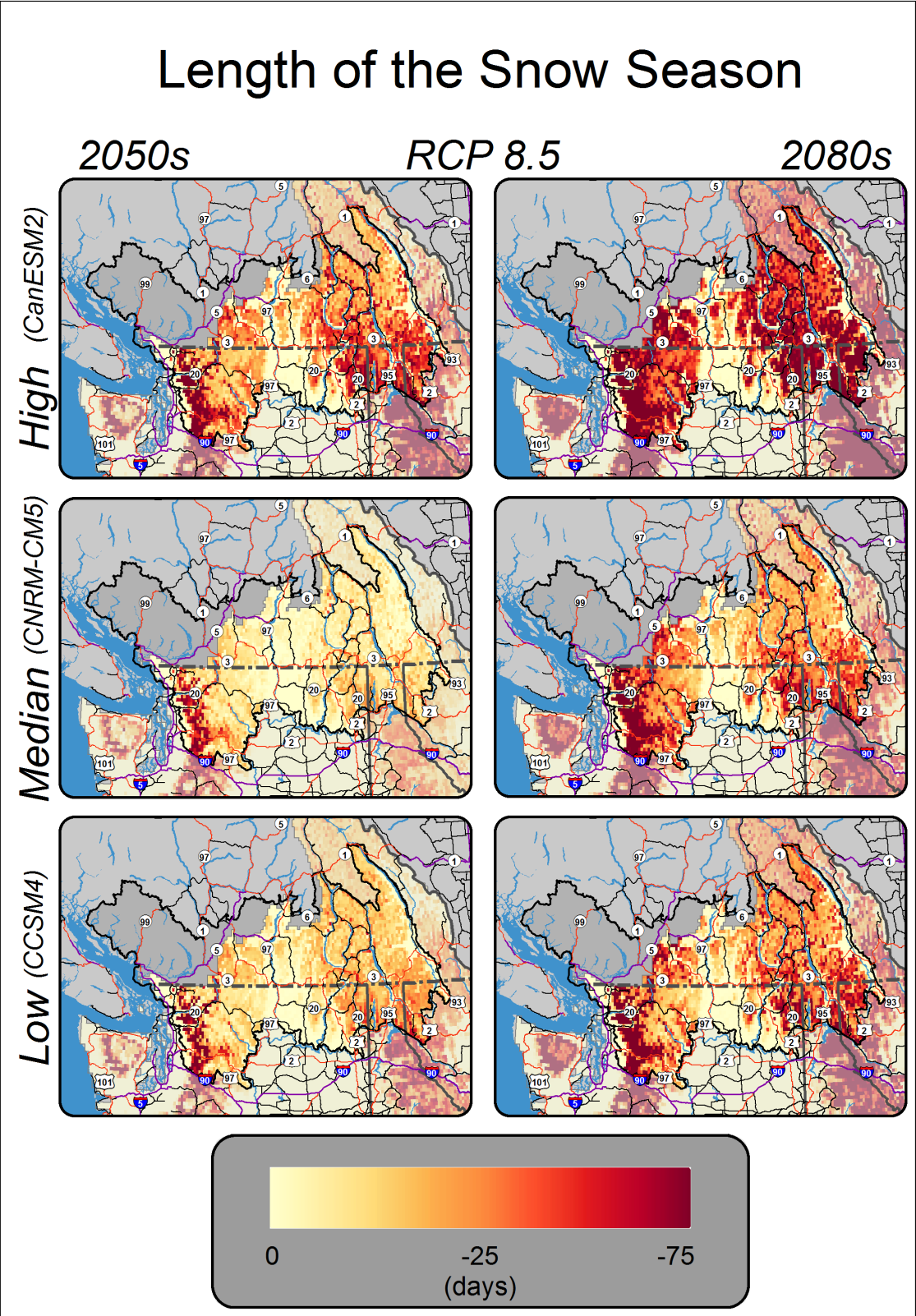**Appendix E.6b. Length of Snow Season**

i) Extent: Okanagan Nation Territory

Appendix E.6b. Length of Snow Season
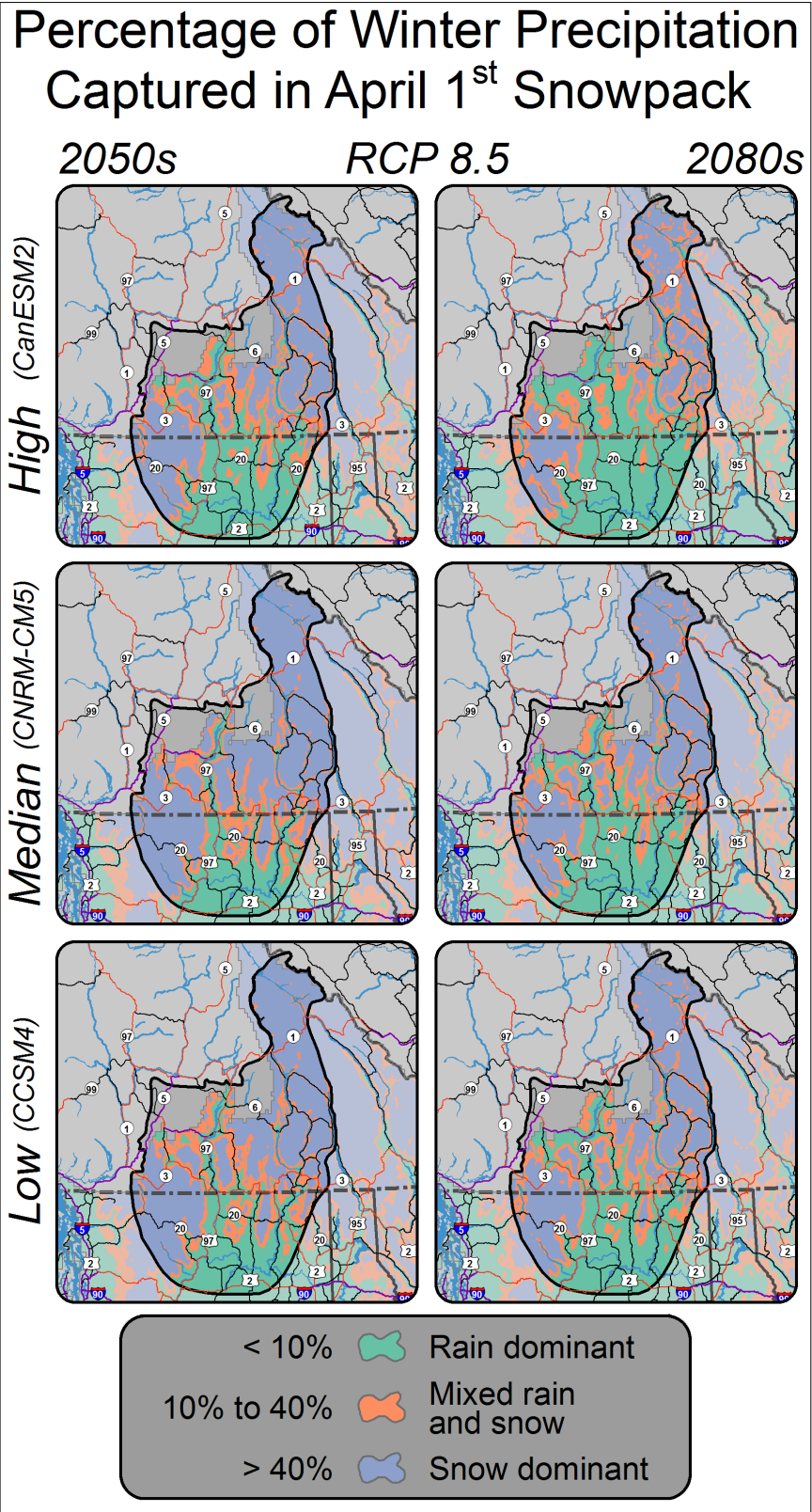
ii) Extent: Okanagan-Kettle Region

Appendix E.6b. Length of Snow Season

iii) Extent: Washington-British Columbia Transboundary Region

Appendix E.6c. Percentage of Winter Precipitation Captured in April 1st Snowpack

i) Extent: Okanagan Nation Territory

Appendix E.6c. Percentage of Winter Precipitation Captured in April 1st Snowpack

ii) Extent: Okanagan-Kettle Region
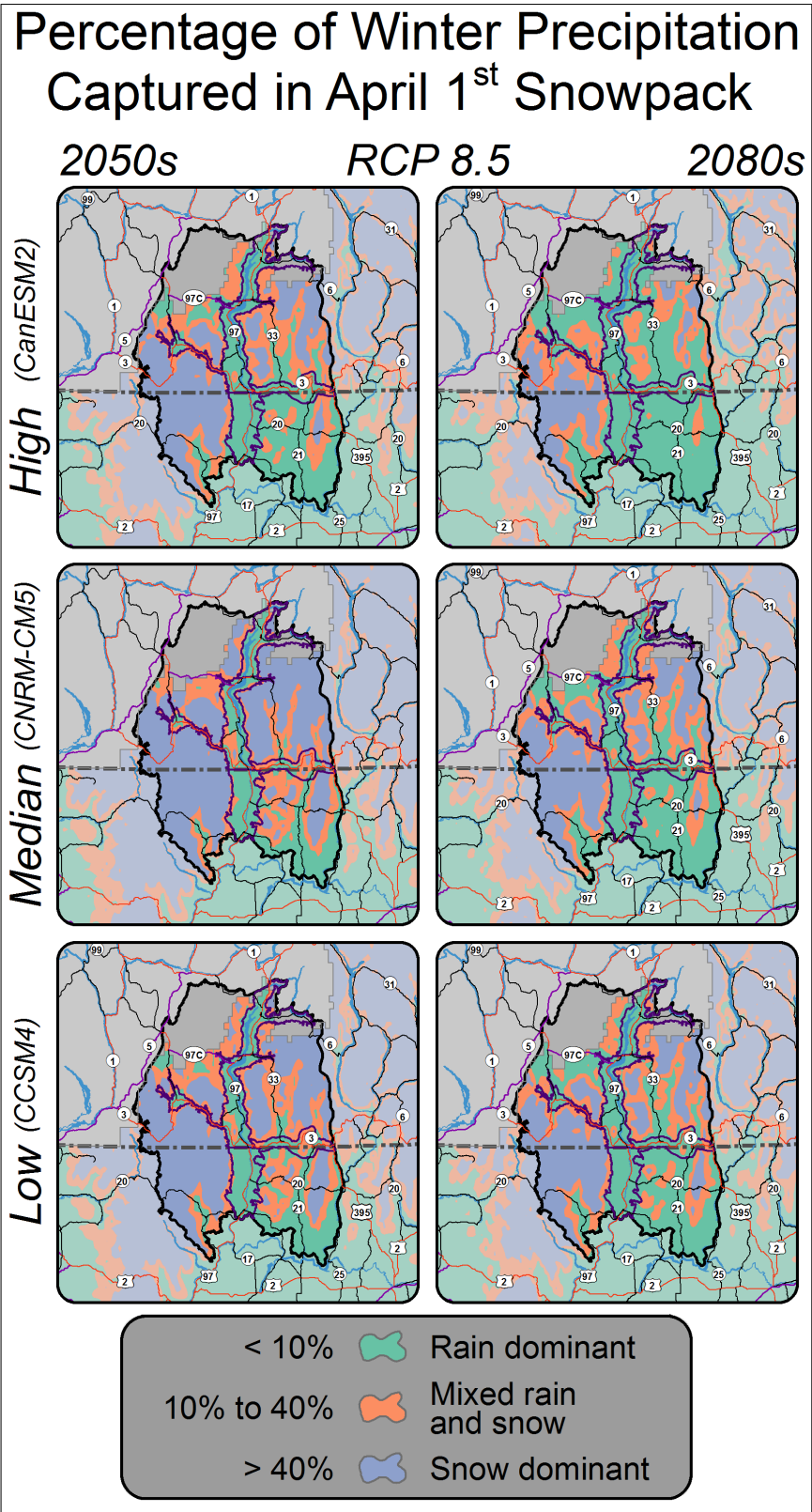
Appendix E.6c. Percentage of Winter Precipitation Captured in April 1st Snowpack

iii) Extent: Washington-British Columbia Transboundary Region
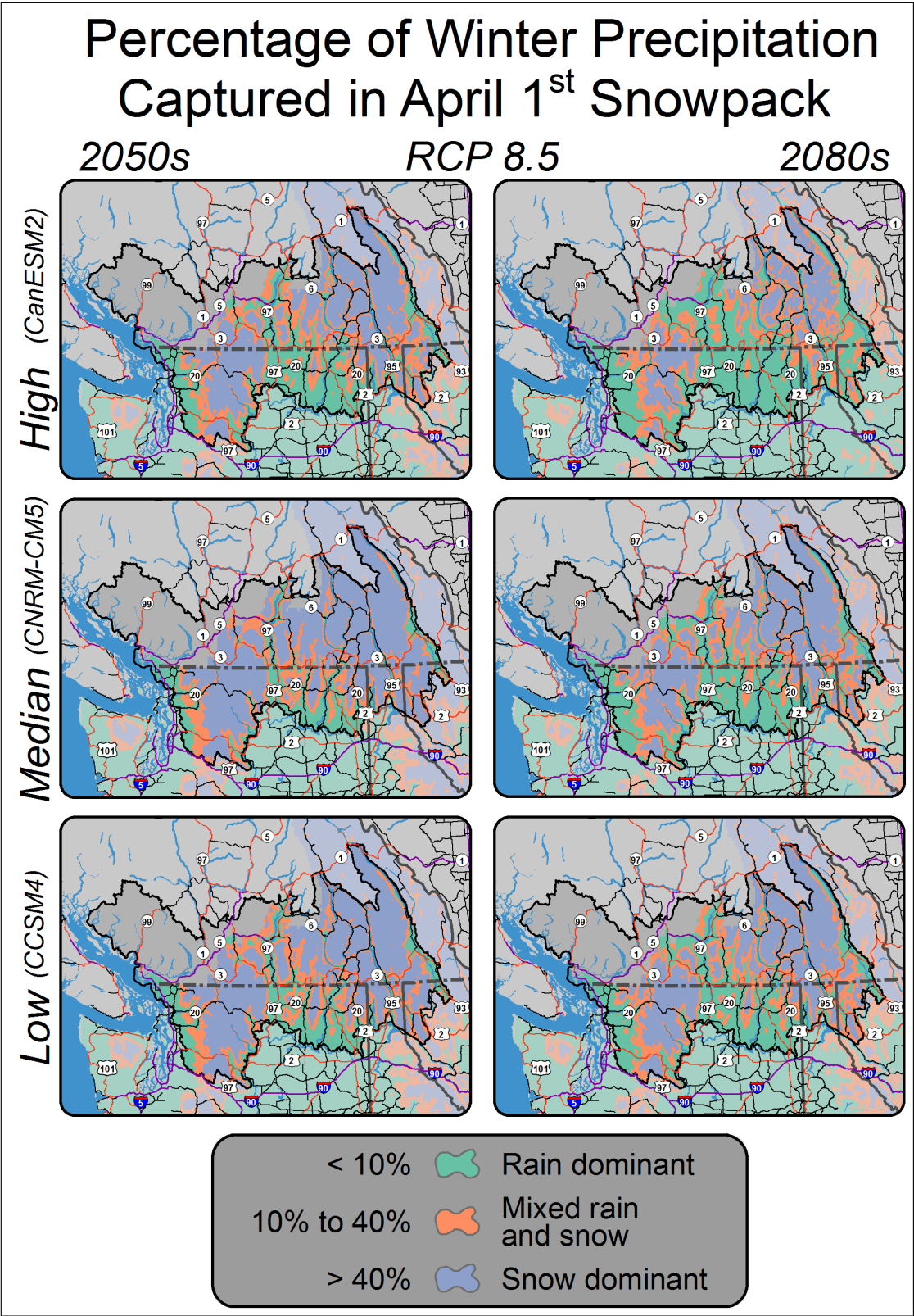
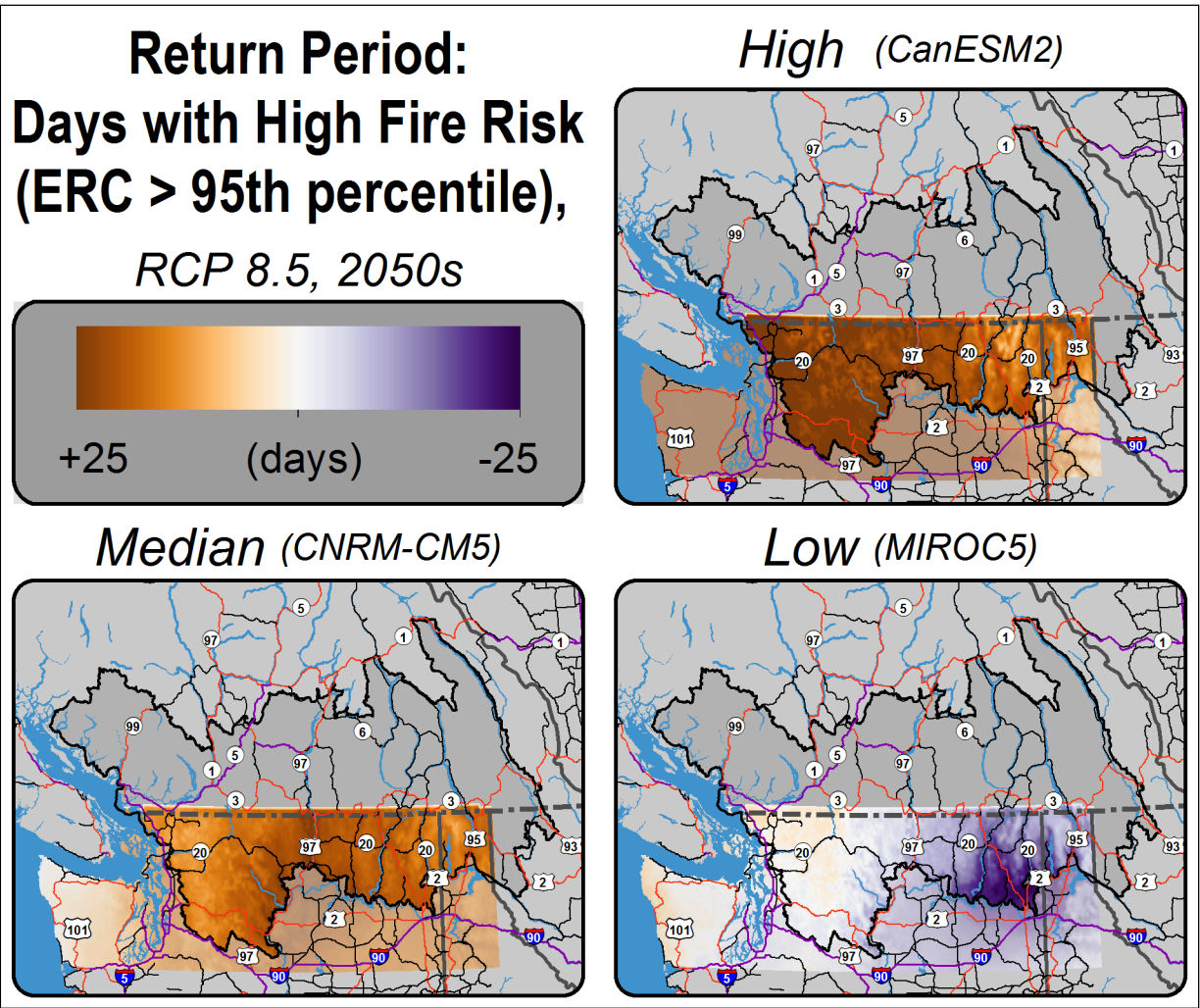**Appendix E.6d. Days with High Fire Risk**

i) Extent: Okanagan Nation Territory
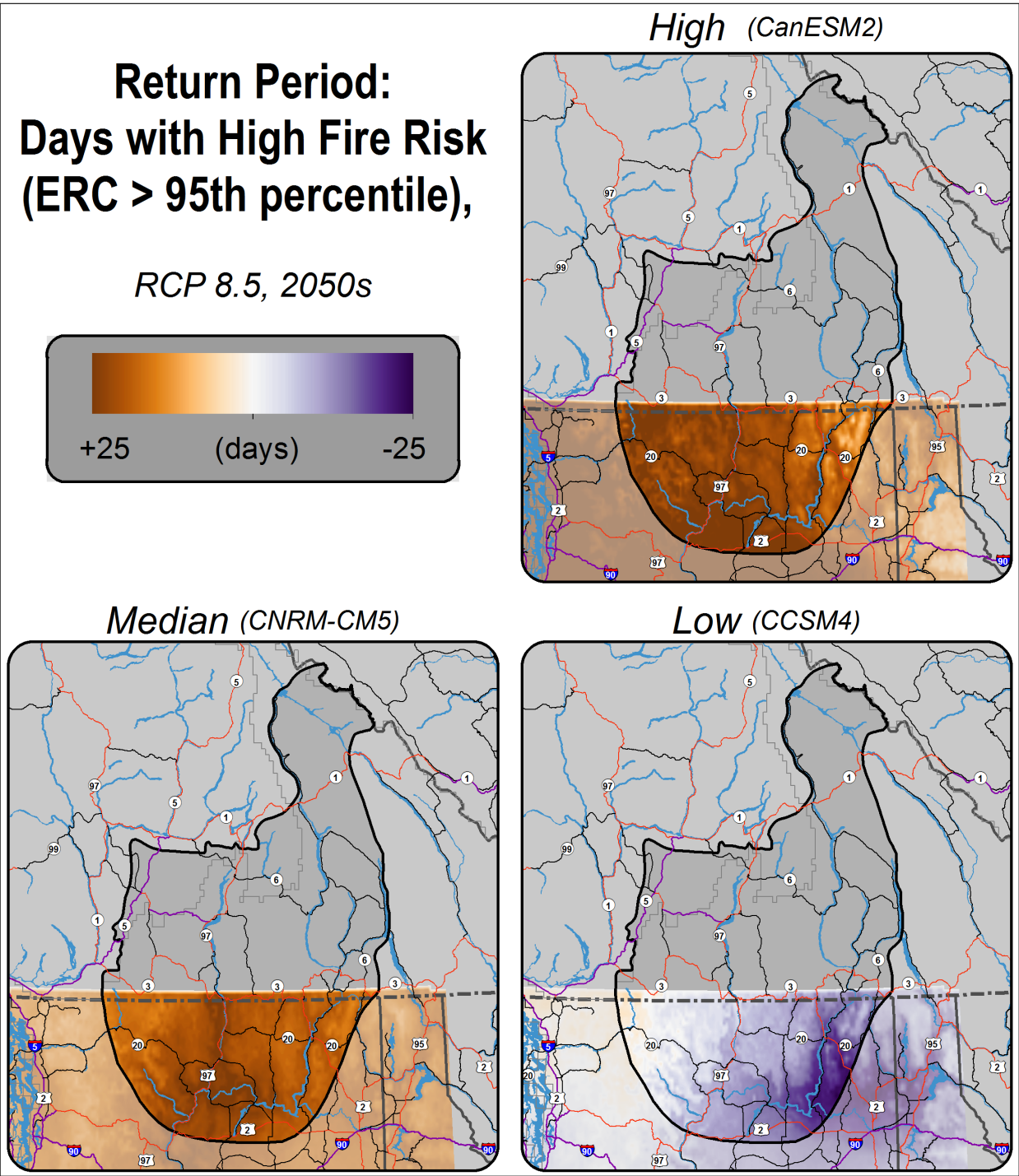
Appendix E.6d. Days with High Fire Risk
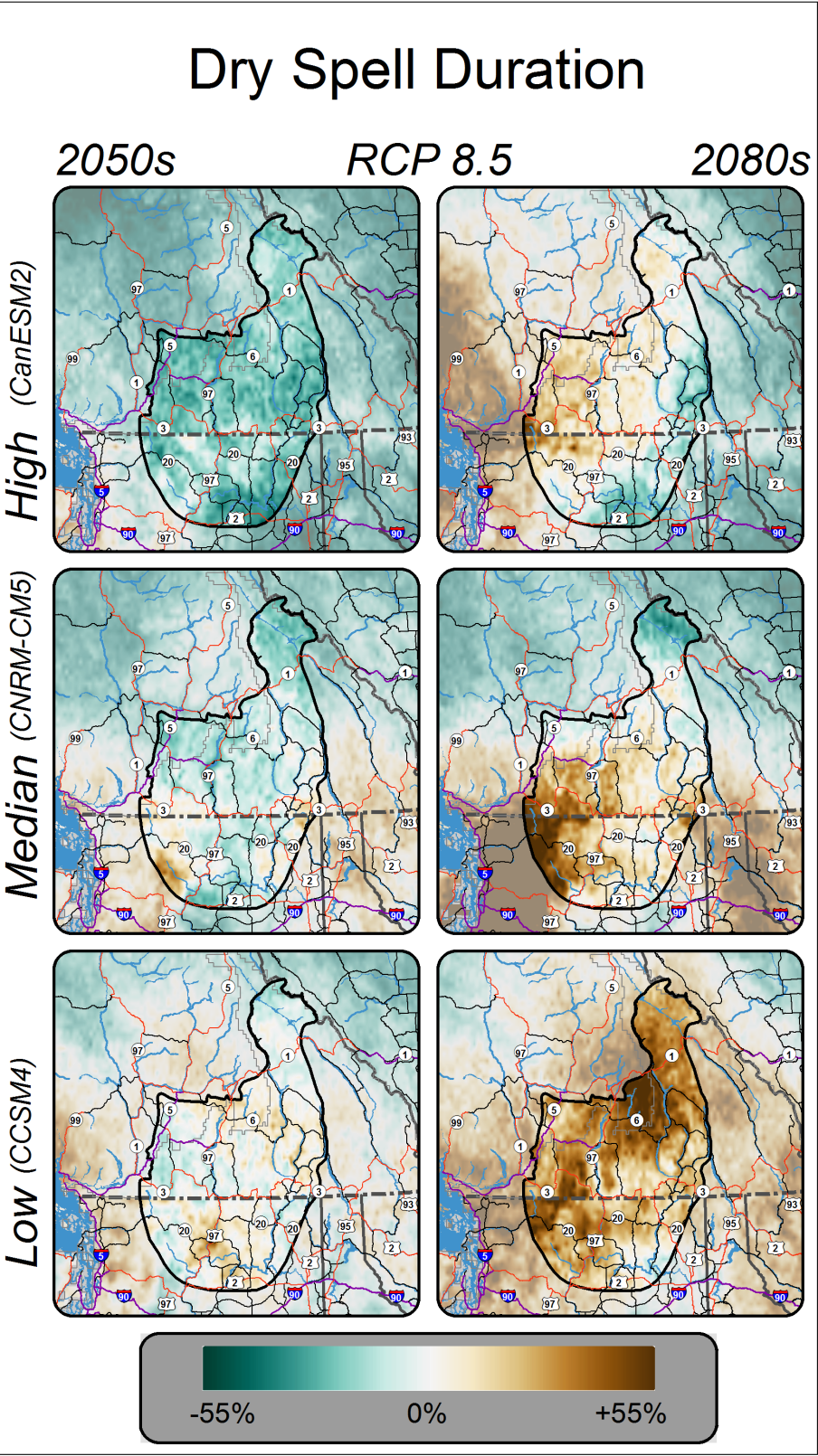
ii) Extent: Okanagan-Kettle Region
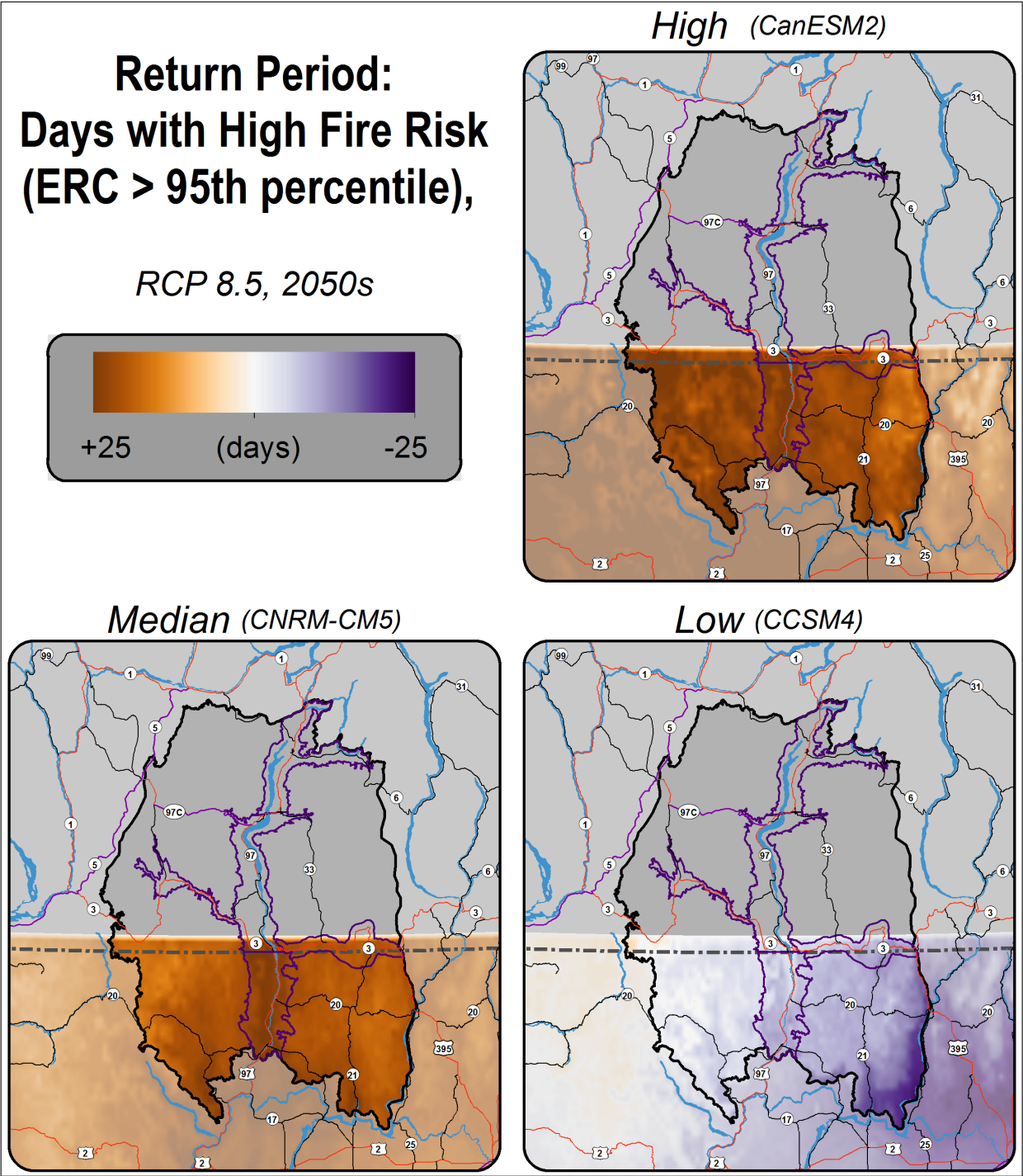
Appendix E.6d. Days with High Fire Risk

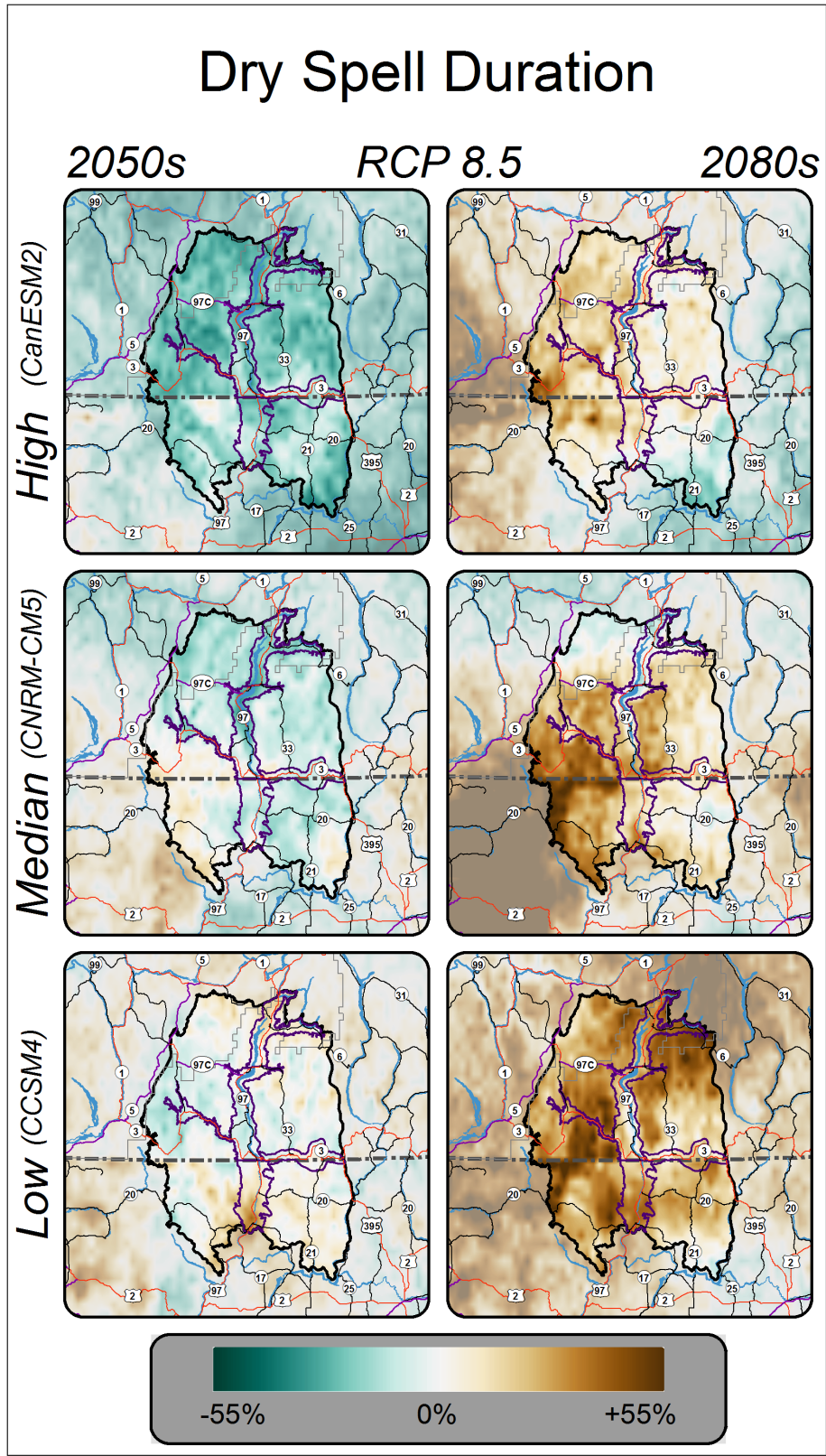iii) Extent: Washington-British Columbia Transboundary Region

Appendix E.6e. Dry Spell Duration

i) Extent: Okanagan Nation Territory

Appendix E.6e. Dry Spell Duration

ii) Extent: Okanagan-Kettle Region

Appendix E.6e. Dry Spell Duration

iii) Extent: Washington-British Columbia Transboundary Region